



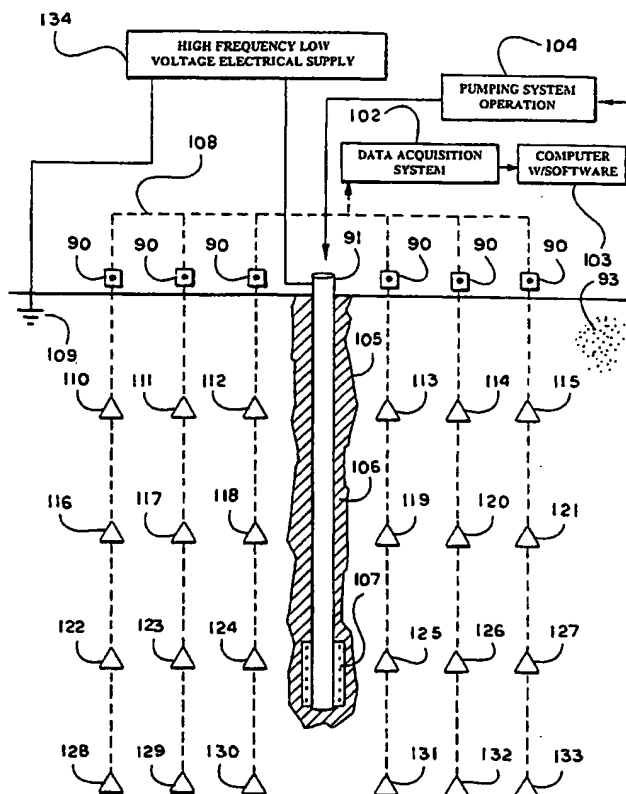
## INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

<b>(51) International Patent Classification <sup>7</sup> :</b> <b>E21B 43/26, 43/267</b>	<b>A2</b>	<b>(11) International Publication Number:</b> <b>WO 00/29716</b> <b>(43) International Publication Date:</b> 25 May 2000 (25.05.00)
<b>(21) International Application Number:</b> PCT/US99/27247 <b>(22) International Filing Date:</b> 17 November 1999 (17.11.99)  <b>(30) Priority Data:</b> 09/193,784 17 November 1998 (17.11.98) US  <b>(71) Applicant:</b> GOLDER SIERRA LLC [US/US]; 3730 Chamblee Tucker Road, Atlanta, GA 30341 (US).  <b>(72) Inventors:</b> HOCKING, Grant; 9315 Delft Way, Alpharetta, GA 30202 (US). WELLS, Samuel; 1212 Napoleon Manor, Lawrenceville, GA 30243 (US).  <b>(74) Agents:</b> CHAN, Christopher, J. et al.; Jones & Askew, LLP, 2400 Monarch Tower, 3424 Peachtree Road, N.E., Atlanta, GA 30326 (US).		<b>(81) Designated States:</b> AU, CA, JP, European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE).  <b>Published</b> <i>Without international search report and to be republished upon receipt of that report.</i>

**(54) Title:** AZIMUTH CONTROL OF HYDRAULIC VERTICAL FRACTURES IN UNCONSOLIDATED AND WEAKLY CEMENTED SOILS AND SEDIMENTS

**(57) Abstract**

The invention is a method and apparatus for initiating an azimuth controlled vertical hydraulic fracture in unconsolidated and weakly cemented soils and sediments using active resistivity to monitor and control the fracture initiation and propagation. Separate or overlapping treatment walls and containment barriers can be created by controlling and monitoring the propagation of fractures in the subsurface. A fracture fluid is injected into a well bore to initiate and propagate a vertical azimuth controlled fracture. The fracture fluid is energized to conduct electrical current while the fracture propagates through the ground. A series of electrical resistivity monitors measure the electrical conductivity of the fracture fluid in real time against the background conductivity of the formation. Using a series of incremental influence functions, the azimuth of the vertical fracture can be controlled by regulating the injection of fracture fluid based upon the induced voltage of the earth and the conductivity of the fluid in the fracture.



**FOR THE PURPOSES OF INFORMATION ONLY**

Codes used to identify States party to the PCT on the front pages of pamphlets publishing international applications under the PCT.

AL	Albania	ES	Spain	LS	Lesotho	SI	Slovenia
AM	Armenia	FI	Finland	LT	Lithuania	SK	Slovakia
AT	Austria	FR	France	LU	Luxembourg	SN	Senegal
AU	Australia	GA	Gabon	LV	Larvia	SZ	Swaziland
AZ	Azerbaijan	GB	United Kingdom	MC	Monaco	TD	Chad
BA	Bosnia and Herzegovina	GE	Georgia	MD	Republic of Moldova	TG	Togo
BB	Barbados	GH	Ghana	MG	Madagascar	TJ	Tajikistan
BE	Belgium	GN	Guinea	MK	The former Yugoslav Republic of Macedonia	TM	Turkmenistan
BF	Burkina Faso	GR	Greece			TR	Turkey
BG	Bulgaria	HU	Hungary	ML	Mali	TT	Trinidad and Tobago
BJ	Benin	IE	Ireland	MN	Mongolia	UA	Ukraine
BR	Brazil	IL	Israel	MR	Mauritania	UG	Uganda
BY	Belarus	IS	Iceland	MW	Malawi	US	United States of America
CA	Canada	IT	Italy	MX	Mexico	UZ	Uzbekistan
CF	Central African Republic	JP	Japan	NE	Niger	VN	Viet Nam
CG	Congo	KE	Kenya	NL	Netherlands	YU	Yugoslavia
CH	Switzerland	KG	Kyrgyzstan	NO	Norway	ZW	Zimbabwe
CI	Côte d'Ivoire	KP	Democratic People's Republic of Korea	NZ	New Zealand		
CM	Cameroon	KR	Republic of Korea	PL	Poland		
CN	China	KZ	Kazakstan	PT	Portugal		
CU	Cuba	LC	Saint Lucia	RO	Romania		
CZ	Czech Republic	LI	Liechtenstein	RU	Russian Federation		
DE	Germany	LK	Sri Lanka	SD	Sudan		
DK	Denmark	LR	Liberia	SE	Sweden		
EE	Estonia			SG	Singapore		

5

1

10

15                   **AZIMUTH CONTROL OF HYDRAULIC VERTICAL  
FRACTURES IN UNCONSOLIDATED AND WEAKLY  
CEMENTED SOILS AND SEDIMENTS**

**TECHNICAL FIELD**

          The present invention generally relates to constructing  
20   subsurface structures by injecting a fracture fluid to fracture  
underground formations, and more particularly to a method and  
apparatus for creating a vertical fracture oriented at a  
predetermined azimuth in unconsolidated and weakly cemented  
soils and sediments resulting in subsurface containment walls and or  
25   treatment barriers.

**BACKGROUND OF THE INVENTION**

          Subsurface structures are installed to perform various  
environmental, geotechnical, and petroleum recovery functions. In  
30   the case of environmental and geotechnical applications,  
containment walls and treatment barriers are typically installed to  
extend from the ground surface to a subsurface zone. In these  
applications, the containment walls may include flow containment  
walls which contain the flow of underground liquids, and treatment  
35   barriers which are permeable zones filled with reactive material. In

5 many cases, the construction process must penetrate many feet below the ground surface before reaching a subsurface zone that requires a structure such as a containment wall or a treatment barrier. Examples of construction techniques performed in the prior art are sheet piling walls, slurry walls, braced excavations, and  
10 continuous trenches.

Current construction techniques required to install the above containment walls and treatment barriers share many common problems, such as the necessity to reroute underground utilities, potential structural damage to existing buildings and structures,  
15 potentially large staging areas for construction equipment, specialized and expensive equipment. In many cases, the removal and proper disposal of contaminated soils and liquids recovered from the excavation is required. Most of the above examples, for either economical or technical reasons, have a maximum wall or  
20 barrier depth that may not allow a project to be completed or even begun.

Turning now to the prior art, hydraulic fracturing of subsurface earth formations to stimulate production of hydrocarbon fluids from subterranean formations has been carried out in many  
25 parts of the world for over fifty years. The earth is hydraulically fractured either through perforations in a cased well bore or in an isolated section of an open bore hole. The horizontal and vertical orientation of the hydraulic fracture is controlled by the compressive stress regime in the earth and the fabric of the  
30 formation. It is well known in the art of rock mechanics that a fracture will occur in a plane perpendicular to the direction of the minimum stress, see U.S. Patent No. 4,271,696 to *Wood*. At significant depth, one of the horizontal stresses is generally at a minimum, resulting in a vertical fracture formed by the hvdraulic

5     fracturing process. It is also well known in the art that the azimuth of the vertical fracture is controlled by the orientation of the minimum horizontal stress.

At shallow depths, the horizontal stresses could be less or greater than the vertical overburden stress. If the horizontal stresses  
10     are less than the vertical overburden stress, then vertical fractures will be produced; whereas if the horizontal stresses are greater than the vertical overburden stress, then a horizontal fracture will be formed by the hydraulic fracturing process.

Techniques to induce a preferred horizontal orientation of the  
15     fracture from a well bore are well known. These techniques include slotting, by either a gaseous or fluid jet under pressure, to form a horizontal notch in an open bore hole. Such techniques are commonly used in the petroleum and environmental industry. The slotting technique performs satisfactorily in producing a horizontal  
20     fracture, provided that the horizontal stresses are greater than the vertical overburden stress, or the earth formation has sufficient horizontal layering or fabric to ensure that the fracture continues propagating in the horizontal plane. Perforations in a horizontal plane to induce a horizontal fracture from a cased well bore have  
25     been disclosed, but such perforations do not preferentially induce horizontal fractures in formations of low horizontal stress. See U.S. Patent No. 5,002,431 to *Heymans*.

Various means for creating vertical slots in a cased well bore have been disclosed. The prior art recognizes that a chain saw can  
30     be used for slotting the casing. See U.S. Patent No. 1,789,993 to *Switzer*; U.S. Patent No. 2,178,554 to *Bowie, et al.*, U.S. Patent No. 3,225,828 to *Wisenbaker*; and U.S. Patent No. 4,119,151 to *Smith*. Installing pre-slotted or weakened casing has also been disclosed in the prior art as an alternative to perforating the casing. See U.S.

5 Patent No. 5,103,911 to *Heijnen*. These methods in the prior art were not concerned with the azimuth orientation of two opposing slots for the preferential initiating of a vertical hydraulic fracture at a predetermined azimuth orientation. It has been generally accepted in the art that the fracture azimuth orientation cannot be controlled  
10 by such means. These methods were an alternative to perforating the casing to achieve better connection between the well bore and the surrounding formation.

In the art of hydraulic fracturing subsurface earth formations from subterranean wells at depth, it is well known that the earth's  
15 compressive stresses at the region of fluid injection into the formation will typically result in the creation of a vertical two "winged" structure. This "winged" structure generally extends laterally from the well bore in opposite directions and in a plane generally normal to the minimum in situ horizontal compressive  
20 stress. This type of fracture is well known in the petroleum industry as that which occurs when a pressurized fracture fluid, usually a mixture of water and a gelling agent together with certain proppant material, is injected into the formation from a well bore which is either cased or uncased. Such fractures extend radially as well as  
25 vertically until the fracture encounters a zone or layer of earth material which is at a higher compressive stress or is significantly strong to inhibit further fracture propagation without increased injection pressure.

It is also well known in the prior art that the azimuth of the  
30 vertical hydraulic fracture is controlled by the stress regime with the azimuth of the vertical hydraulic fracture being perpendicular to the minimum horizontal stress direction. Attempts to initiate and propagate a vertical hydraulic fracture at a preferred azimuth orientation have not been successful, and it is widely believed that

5 the azimuth of a vertical hydraulic fracture can only be varied by changes in the earth's stress regime. Such alteration of the earth's local stress regime has been observed in petroleum reservoirs subject to significant injection pressure and during the withdrawal of fluids resulting in local azimuth changes of vertical hydraulic  
10 fractures.

The determination of the hydraulic fracture geometry, such as its horizontal or vertical orientation, azimuth and length of the vertical fracture, and the extent and depth of a horizontal fracture, can be made from the measurement of earth tilts by conventional  
15 surface or bore hole mounted biaxial tiltmeters, see U.S. Patent No. 4,271,696 to *Wood*. Highly sensitive electronic tiltmeters, capable of measuring tilts less than  $10^{-7}$  radians, measure the earth's deformation due to the opening and propagation of a hydraulic fracture. From monitoring these tilts in real time along with the  
20 flow of injected fluid, the hydraulic fracture geometry can be determined. See U.S. Patent Nos. 4,271,696 and 4,353,244 to *Wood*. Influence functions that relate the opening of a fracture to ground deformation can be utilized to calculate the fracture geometry. As suggested by U.S. Patent No. 5,002,431 to *Heymans*,  
25 the fracture geometry can be determined and controlled from the measurement of tilts and real time computer control. *Heymans* does not detail how the fracture geometry may be determined, nor does *Heymans* disclose how the interaction of ground tilts from multiple fractures can be resolved to determine fracture geometry.

30 The method of determining the hydraulic fracture geometry, disclosed by U.S. Patent No. 4,353,244 to *Wood*, has a number of deficiencies. If (a) the fracture is non-planar, (b) if the fracture is not of the full initiated height, or (c) if multiple fractures are initiated in

5 close proximity of each other, then fracture geometry determination is not assured.

Accordingly, there is a need for a method and apparatus for controlling the azimuth orientation of a vertical hydraulic fracture in formations of unconsolidated or weakly cemented sediments and  
10 soils.

There is a further need for a method and apparatus for monitoring and calculating in real time the propagation of the azimuth of vertical hydraulic fractures.

And, there is a further need for a method and apparatus for  
15 the creation and control of coalesced, overlapping, and interconnecting fractures to form a treatment barrier or containment wall formed from a fracture fluid.

## SUMMARY OF THE INVENTION

20 The present invention is a method and apparatus for dilating the earth by various means from a bore hole or driven lance to initiate and to control the azimuth orientation of a vertical hydraulic fracture in formations of unconsolidated or weakly cemented sediments. The fracture is initiated by means of preferentially  
25 dilating the earth orthogonal to the desired azimuth direction. This dilation of the earth can be generated by a variety of means: a driven spade to dilate the ground orthogonal to the required azimuth direction, packers that inflate and preferentially dilate the ground orthogonal to the required azimuth direction, pressurization  
30 of a pre-weakened casing with the weaknesses aligned in the required azimuth orientation, pressurization of a casing with opposing slots cut along the required azimuth direction, or pressurization of a two "winged" artificial vertical fracture



5 generated by cutting or slotting the casing, grout, and/or formation at the required azimuth orientation.

In addition to initiation of vertical fractures at a predetermined azimuth, the present invention further provides a method and apparatus for monitoring and controlling the  
10 propagation of the fractures along the predetermined azimuth. The present invention relies upon the determination of influence functions that relate the earth's deformation to the opening of an elementary fracture.

Using generally accepted principles of elasticity theory,  
15 influence functions such as Green's functions can be applied to the problem. See "Hydrodynamics" by H. Lamb, 4<sup>th</sup> edition, Cambridge (1916) and "Treatise on Mathematical Theories of Elasticity" by A.E.H. Love, 4<sup>th</sup> edition, Dover Publications (1944). If a series of Green's functions can be solved relating incremental  
20 measurements of the earth's induced voltage or deformation with the geometry change in an initiated fracture, then a sequential incremental solution can be determined. With a series of sequential incremental solutions, an inverse model can be created for a particular type of soil and sediment formation or for a specific  
25 formation. The geometry of the fracture can then be calculated during the injection process by a series of sequential incremental solution calculations involving the inverse model. Utilizing either measured ground tilts or measured induced voltages from electrifying the fracturing fluid, the user monitors the injected flow  
30 of the injected fluid to determine and control the in situ geometry of the fracture during the injection process.

Thus, by relating measured incremental ground tilts or measured induced voltages to yield incremental change of the fracture geometry constrained by the incremental volume of

5 injected fluid into each fracture, the incremental change in geometry of each fracture is found by minimizing the differences in the computed and measured incremental tilts or induced voltages. The essential difference between the present invention and the prior art is the utilization of a sequential incremental solution to determine  
10 incremental fracture geometry changes as the fracture is propagating. Such a method yields the fracture geometry at a particular time during the injection process. Without a sequential incremental solution method to determine the in situ fracture geometry, the system of equations is poorly defined, and a large  
15 range of differing geometry of fractures can fit or yield the same tilt field.

The present method and apparatus determine the fracture geometry by active resistivity after initiating a hydraulic fracture in moderate to highly resistive ground conditions. The fracture fluid is  
20 electrically conductive and is electrically energized by an alternating electrical source, typically a 100 Hz low voltage source. Real time instrumentation monitors resistivity receivers for surface and sub-surface induced voltages of the 100 Hz signal due to the energized fracture fluid in the propagating fracture. Surface and  
25 sub-surface induced voltages are recorded. By utilizing potential influence functions of the induced voltage in the earth due to an elementary electrified fracture, and from an incremental inverse model constrained by the incremental volume of injected fluid, the fracture geometry is determined in real time during the injection  
30 process.

The active resistivity method of monitoring fracture geometry requires that the fracture fluid be at least twenty times more conductive than the surrounding ground, to ensure a sharp signal and high contrast between the fracture and the surrounding

5 medium. In this case, the energized fracture can be approximated as an electrified sheet, and potential influence functions of the earth's induced voltages from an elementary electrified fracture can be formulated. The fracture fluid can be made conductive by the addition of soluble salts or by the selection of a suitable fracture  
10 fluid that has a high conductivity. Fracture fluids suitable for this method and apparatus can comprise, but are not limited to, a water based guar gum gel for a permeable treatment barrier and a bentonite cement slurry for an impermeable containment barrier.

From real time monitoring of the earth's induced voltages  
15 due to the propagating electrified fracture and from the flow of injected fluid into the fracture, the geometry of the fracture can be determined. Influence functions relate the earth's induced voltage to the propagation of an elementary electrified fracture. By solving the inverse problem of measured incremental induced voltages to  
20 yield fracture incremental geometry change constrained by the incremental volume of injected fluid into each fracture, the incremental change in geometry of each fracture can be found by minimizing the differences in the computed and measured incremental induced voltages.

25 If the initiated hydraulic fracture is relatively deep, down hole resistivity receivers are used to obtain a high precision image of the energized fracture. Active resistivity monitoring has the added benefit of determining when individual fractures coalesce and thus become electrically connected. That is, by energizing the fracture  
30 fluid in each injected well bore individually and in unison, the electrical coalescence of multiple fractures from different well bores can be clearly recorded and observed. The imaging and observation of the down hole resistivity data focuses on quantifying the continuity of the fractures and assessing the fracture continuity

5 to determine if any holes or gaps are present. Such monitoring allows construction procedures to be modified to ensure the hydraulic fractures are installed as planned and allows contingency measures to be implemented immediately, e.g. an additional fracture to patch any hole or additional injection volumes to ensure  
10 coalescence or sufficient overlap.

The present invention also pertains to a method for constructing subsurface structures including containment walls or treatment barriers by injecting a liquid slurry into an azimuth controlled hydraulic fracture or fractures to form either a  
15 continuous or overlapping system of fractures. By initiating and propagating azimuth orientated vertical hydraulic fractures from a series of bore holes aligned in the required azimuth direction, coalesced and overlapping fractures are created to form a containment wall or treatment barrier composed of the fracture  
20 fluid. The process of monitoring and calculating the fracture in situ geometry during the injection process, enables determination of when to cease injection or whether to continue injection to achieve the required shape, extent, coalescence, or degree of overlap of the azimuth orientated vertical hydraulic fractures.

25 The fracture fluid used to form the containment walls and treatment barriers in the vertical fractures has two purposes. First the fracture fluid must be formulated in order to initiate and propagate the fracture within the underground formation. In that regard the fracture fluid has certain attributes. The fracture fluid  
30 fracture fluid should not leak off into the formation, the fracture fluid should be clean breaking with minimal residue, and the fracture fluid should have a low friction coefficient.

Second, once injected into the fracture, the fracture fluid forms the containment wall or the treatment barrier. In that regard,

5 the fracture fluid comprises a proppant which produces the integrity  
for a containment wall or the active component for a treatment  
barrier. Such proppants for containment walls may include, for  
example, perlite in a bentonite cement slurry. Such proppants for  
treatment barriers may include, for example, iron filings. The  
10 proppants are selected and formulated to accomplish the purpose  
intended for the containment wall or the treatment barrier.

The present invention is applicable only to formations of  
unconsolidated or weakly cemented sediments and soils with low  
cohesive strength compared to the vertical overburden stress  
15 prevailing at the depth of the hydraulic fracture. Low cohesive  
strength is defined herein as the greater of 200 pounds per square  
inch (psi) or 25% of the total vertical overburden stress. The  
method is not applicable to consolidated rock formations, in which  
the fracture azimuth is controlled by the rock formation stress  
20 regime.

Although the present invention contemplates the formation of  
fractures which generally extend laterally away from a vertical or  
near vertical well penetrating an earth formation and in a generally  
vertical plane in opposite directions from the well, i.e. a vertical two  
25 winged fracture, those skilled in the art will recognize that the  
invention may be carried out in earth formations wherein the  
fractures and the well bores can extend in directions other than  
vertical.

Therefore, the present invention provides a method and  
30 apparatus for controlling the azimuth of a vertical hydraulic fracture  
in formations of unconsolidated or weakly cemented sediments and  
soils.

The present invention also provides a method and apparatus  
for the creation and control of coalesced, overlapping, and

5 interconnecting fractures to form a containment barrier or treatment wall.

Further, the present invention provides a method and apparatus for monitoring and calculating in real time the propagation of a vertical hydraulic fracture.

10 Other objects, features and advantages of the present invention will become apparent upon reviewing the following description of the preferred embodiments of the invention, when taken in conjunction with the drawings and the claims.

#### 15 BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a plan view of two injection well casings depicting the design centerline of the fracture wall before the azimuth controlled vertical hydraulic fractures are initiated.

20 FIG. 2 is a cross-sectional side view of the installed injection well casings as shown in FIG. 1.

FIG. 3 is an enlarged plan view of an individual pre-fracture injection well casing as shown in FIGs. 1 and 2.

25 FIG. 4 is an enlarged plan view of an individual pre-fracture injection well casing with a slot cut through the injection casing wall and grout, where the slot is aligned with the design centerline of the fracture wall.

FIG. 5 is a cross-sectional side view of an individual pre-fracture injection well casing with the length of a vertical slot shown.

30 FIG. 6 is an enlarged plan view of an individual injection well casing during initial propagation of the azimuth controlled vertical fracture.

5        FIG. 7 is a cross-sectional side view of two injection casings with winged initiation sections of the injection casing construction for azimuth controlled vertical fracture initiation.

      FIG. 8 is a plan view detail of the fabrication and installation of the winged initiation sections of the injection casing construction  
10 prior to initiation of the azimuth controlled vertical fracture.

      FIG. 9 is a plan view detail of the initiation of an azimuth controlled vertical fracture from a winged initiation section of the injection casing construction.

      FIG. 10 is a plan view of an individual injection well casing  
15 with locations of the vertical installed resistivity arrays, parallel and offset to the design centerline of the azimuth controlled vertical fracture that has not yet been initiated.

      FIG. 11 is a cross-sectional side view showing the construction detail and arrangement of a resistivity sensor array.

20        FIG. 12 is a cross-sectional side view of a single resistivity array showing the locations of individual resistivity receivers.

      FIG. 13 is cross-sectional side view of the initial start of an azimuth controlled vertical fracture superimposed on FIG. 11.

      FIG. 14 is a cross-sectional side view of the final design  
25 geometry of an azimuth controlled vertical fracture superimposed on FIG. 11.

      FIG. 15 is the visual display of an arrangement of individual resistivity receivers in a ground formation prior to initiation of an azimuth controlled vertical fracture in the subsurface.

30        FIG. 16 is the visual display showing the measured voltages of the individual resistivity receivers against background reference voltages illustrating a propagating azimuth controlled vertical fracture in the subsurface.

5 DETAILED DESCRIPTION OF THE DISCLOSED EMBODIMENT

Several embodiments of the present invention are described below and illustrated in the accompanying drawings. The present invention involves a method and apparatus for initiating and  
10 propagating an azimuth controlled vertical fracture in subsurface formations of unconsolidated and weakly cemented soils and sediments. In addition, the present invention involves a method and apparatus for controlling and monitoring the fracture initiation, propagation, and geometry of a vertical fracture.

15 Referring to the drawings, in which like numerals indicate like elements, FIGs. 1, 2, and 3 illustrate the initial setup of the method and apparatus. Conventional bore holes 5 and 5' with axes 12 and 12' are completed by an auger, wash rotary, or cable tool methods into the formation 6 of unconsolidated or weakly cemented soils and sediments to a predetermined depth 9 below the ground surface  
20 4 on the predetermined fracture line or plane 3 of the planned azimuth controlled vertical fracture. The fracture plane 3 extends radially from axis 12 to axis 12'. Injection casings 1 and 2 are installed to the predetermined to depth 9 and completed by  
25 placement of a grout 7 which completely fills the annular space between the outside the injection casings 1 and 2 and the bore holes 5 and 5'. Injection casings 1 and 2 must be constructed from a material that can withstand the pressures that the fracture fluid exerts upon the interior of the injection casings 1 and 2 during the  
30 pressurization of the fracture fluid. The grout 7 can be any conventional material that preserves the spacing between the exterior of the injection casings 1 and 2 and the bore holes 5 and 5' throughout the fracturing procedure, preferably a non-shrink or low shrink cement based grout.



5           The outer surface of the injection casings **1** and **2** should be roughened or manufactured such that the grout **7** bonds to the injection casings **1** and **2** with a minimum strength equal to the down hole pressure required to initiate an azimuth controlled vertical fracture. The bond strength of the grout **7** to the outside  
10 surface of the casings **1** and **2** prevents the pressurized fracture fluid from short circuiting along the casing-to-grout interface up to the ground surface **4**.

          Referring to FIGs. 4 and 5, a casing cutter can be lowered into the injection casing **2** to a predetermined depth **11**, and the  
15 injection casing **2** is cut vertically and parallel to the fracture plane **3** of the planned azimuth controlled vertical fracture. The lateral depth of cut shown in FIG. 4 is completely through the wall of injection casing **2** and through the majority of the grout **7**. The length **10** of the vertical cut **8** into the injection casing **2** and the  
20 grout **7** is dependent upon the required size of the planned azimuth controlled vertical fracture, the site specific soil **6** type, and the in situ stress conditions within the soil **6**. The lateral depth of the vertical cut **8** to control the azimuth of the vertical fracture may require laterally extending the vertical cut **8** into the surrounding  
25 soil **6**. When this additional depth of vertical cut **8** is necessary, the resulting notch into the soil **6** is kept open prior to initiation of the vertical fracture.

          Referring to FIG. 6, once the fracture is initiated, injection of a fracture fluid **20** through the injection casing **2**, vertical cut **8**,  
30 grout **7**, and into the initiated fracture **21** can be made by any conventional means to pressurize the fracture fluid **20**. The conventional means can include any pumping arrangement to place the fracture fluid **20** under the pressure necessary to transport the fracture fluid **20** into the initiated fracture **21** to assist in fracture

5 propagation and to create a subsurface containment wall or  
treatment barrier. For successful fracture initiation and propagation  
to the desired size with maximum spacing of the injection casings 2,  
the preferred embodiment of the fracture fluid 20 should have the  
following characteristics. The fracture fluid 20 should not  
10 excessively leak off or lose its liquid fraction into the adjacent  
unconsolidated soils and sediments. The fracture fluid 20 should be  
able to carry the solids fraction (the proppant) of the fracture fluid  
20 at low flow velocities that are encountered at the edges of a  
maturing azimuth controlled vertical fracture. The fracture fluid 20  
15 should have the functional properties for its end use such as  
longevity, strength, reactivity, permeability, etc. The fracture fluid  
20 should be at least twenty times more conductive than the  
unconsolidated or weakly cemented soils and sediments in order to  
obtain sufficient electrical contrast for active resistivity methods for  
20 tracking the in situ geometry of the propagating azimuth controlled  
vertical fracture.

Permeable groundwater treatment barriers can be  
constructed by orientated vertical hydraulic fractures filled with a  
fracture fluid 20 having a treatment proppant. Treatment proppants  
25 can be reactive, absorbent or adsorbent, precipitates or

5 biodegradable, depending upon the groundwater contaminants of concern. Reactive proppants can comprise, without limitation, the following: iron filings for the dechlorination of chlorinated solvents, such as organic contaminants: trichloroethane (TCE), cis 1,2-dichloroethane (cDCE), tetrachloroethene (PCE), 1,1-dichloroethene  
10 (11DCE), 1,1,1 Trichloroethane (111TCA), chloroform (TCM), carbon tetrachloride (CT) and vinyl chloride (VC). Absorbent or adsorbent proppants can comprise, without limitation, the following: activated alumina, activated carbon and resins for the absorption of metals, phosphate, nitrate, hydrocarbons, etc. Precipitation  
15 proppants comprise, without limitation, the following: iron filings for metal precipitation, and lime and slag for phosphate removal. Biodegradation proppants can comprise, without limitation, the following: enzyme, microbes, nutrients, growth substrates, etc. to achieve in situ biodegradation of the particular contaminant.

20 The fracture fluid 20 should be compatible with the proppant, the subsurface formation, and the formation fluids. Further, the fracture fluid 20 should be capable of controlling the viscosity of the proppant, and for carrying the proppant through the formation fracture. The fracture fluid 20 should be an efficient fluid, i.e. low  
25 leak off from the fracture into the formation, to be clean breaking with minimal residue, and to have a low friction coefficient. The fracture fluid 20 should not excessively leak off or lose its liquid fraction into the adjacent unconsolidated formation. For a permeable treatment barrier, the gel composed of starch should be  
30 capable of being degraded leaving minimal residue and not impart the properties of the fracture proppant. A low friction coefficient fluid is required to reduce pumping head losses in piping and down the well bore. When a hydraulic fracture permeable treatment barrier is desired, typically a gel is used with the proppant and the

5 fracture fluid. Preferable gels can comprise, without limitation of the following: a water-based guar gum gel, hydroxypropylguar (HPG), a natural polymer or a cellulose-based gel, such as carboxymethylhydroxyethylcellulose (CMHEC). The gel is chosen for its minimal impact on the proppant material properties, such as  
10 reactivity, absorption, etc., and the extremely low gel residue in the treatment barrier once the enzyme has been degraded.

The gel is generally cross-linked to achieve a sufficiently high viscosity to transport the proppant to the extremes of the fracture. Cross-linkers are typically metallic ions, such as borate, antimony,  
15 zirconium, etc., disbursed between the polymers and produce a strong attraction between the metallic ion and the hydroxyl or carboxy groups. The gel is water soluble in the uncrossed-linked state and water insoluble in the cross-linked state. While cross-linked, the gel can be extremely viscous thereby ensuring that the  
20 proppant remains suspended at all times. An enzyme breaker can be added to controllably degrade the viscous cross-linked gel into water and sugars. The enzyme typically takes a number of days to biodegrade the gel, and upon breaking the cross-link and degradation of the gel, a permeable treatment wall of the proppant  
25 remains in the ground with minimal gel residue. For certain proppants, pH buffers can be added to the gel to ensure the gel's in situ pH is within a suitable range for enzyme activity. Salts comprising, but not limited to, sodium chloride, potassium chloride, and potassium bromide are added to the gel to achieve a sufficiently  
30 high gel electrical conductivity for mapping of the fracture geometry by the active resistivity method.

The fracture fluid-gel-proppant mixture is injected into the formation and carries the proppant to the extremes of the fracture. Upon propagation of the fracture to the required lateral and vertical

5 extent, the predetermined fracture thickness may need to be increased by utilizing the process of tip screen out. This process involves modifying the proppant loading and/or fracture fluid 20 properties to achieve a proppant bridge at the fracture tip. The fracture fluid 20 is further injected after tip screen out, but rather  
10 then extending the fracture laterally or vertically, the injected fluid widens the fracture.

Impermeable flow containment walls constructed by oriented vertical hydraulic fracturing are typically composed of, without limitation, bentonite cement slurries with or without special additives  
15 for improving leak off performance, delaying setting time, and reducing water-to-cement ratios. The bentonite acts as the prime filter cake building material in the fracture fluid 20, but can be replaced by alternative materials, without limitation, such as silica flour and perlite. Generally, bentonite cement slurry has a  
20 sufficiently high electrical conductivity for the active resistivity mapping technique.

The density of the fracture fluid 20 can be altered by increasing or decreasing the proppant loading or modifying the density of the proppant material. In many cases, the fracture fluid  
25 20 density will be controlled to ensure the fracture propagates downwards initially and achieves the required height of the planned structure. Such downward fracture propagation requires the gel density to be typically greater than 1.25 gm/cc.

The viscosity of the fracture fluid 20 should be sufficiently  
30 high to ensure the proppant remains suspended during injection into the subsurface, otherwise dense proppant materials will sink or settle out and light proppant materials will flow or rise in the fracture fluid 20. The required viscosity of the fracture fluid 20 depends on the density contrast of the proppant and the gel and the proppant's

5 maximum particulate diameter. For medium grain-size iron filings, that is of grain size similar to a medium sand, a fracture fluid 20 viscosity needs to be typically greater than 100 centipoise at a shear rate of 1/sec.

Referring to FIGs. 4, 5, and 14, the fracture is initiated by  
10 pumping the fracture fluid 20 with a pumping system 104 through the injection casing 2, 91 to the previously slotted injection casing 2, 91 and grout 7, 106. As best shown in FIG. 4, when the pressure of the fracture fluid 20 increases, the fracture fluid 20 will exert lateral forces 19 on the interior of the injection casing 2 and the  
15 interior of the vertical cut 8. The lateral forces 19 will be perpendicular to the fracture plane 3 of the planned azimuth controlled vertical fracture. The injection casing 2 and grout 7 are shown to be separating in the direction perpendicular to the fracture plane 3 of the planned azimuth controlled vertical fracture.

20 As best shown in FIG. 6, when the pressure of the fracture fluid 20 is increased to a level which exceeds the lateral earth pressures, the grout 7 which is bonded to the injection casing 2 will begin to dilate the adjacent soil 6 forming a parting 21 of the soil 6 along the fracture plane 3 of the planned azimuth controlled vertical  
25 fracture. The fracture fluid 20 rapidly fills the parting 21 of the soil 6 in the vertical cut 8. Within the injection casing 2, the fracture fluid 20 exerts normal forces on the soil 6 perpendicular to the fracture plane 3 which progressively extends the parting 21 and continues to maintain the required azimuth of the initiated fracture.  
30 The azimuth controlled vertical fracture will be expanded by continuous pumping of the fracture fluid 20 until the desired geometry is achieved.

In another embodiment for azimuth controlled vertical fracture initiation refer to FIGs. 7, 8, and 9. As best shown in FIG.

5 7, conventional bore holes 51 can be completed by an auger, wash rotary, or cable tool methods below the ground surface 57 to the required depth. Injection casings 50 along with wing initiation sections 52, 53, 54, 55 are installed at predetermined depths within the bore holes 51. The wing initiation sections 52, 53, 54, 55 can be  
10 constructed from the same material as the injection casings 50. The wing initiation sections 52, 53, 54, 55 are aligned parallel and through the fracture plane 83 of the pre-constructed azimuth controlled vertical fracture. The alignment of the wing initiation sections 52, 53, 54, 55 to the fracture plane 83 can be performed by  
15 a conventional down hole camera with an attached magnetic compass or by a down hole gyroscopic instrument before the grout 56 is placed in the annular space between the bore hole 51 and the injection casings 50 and the wing initiation sections 52, 53, 54, 55. The outer surface of the injection casings 51 and of the wing  
20 initiation sections 52, 53, 54, 55 should be a roughened or manufactured surface such that the bond of the grout 56 is greater than the fracture initiation pressure. The position below ground surface of the winged initiation sections 52, 53, 54, 55 will depend on the required in situ geometry site specific soil properties and the  
25 in situ soil stresses.

The winged initiation sections 52, 53, 54, 55 are preferably constructed from two symmetrical halves 84, 85 as shown in FIGs. 8 and 9. The configuration of the winged initiation sections 52, 53, 54, 55 is not limited to the shape shown, but the chosen  
30 configuration must permit the initiating fracture to propagate laterally in at least two opposing directions away from the fracture plane 83 of the winged initiation sections 52, 53, 54, 55. In FIG. 8, prior to initiating the fracture, the two symmetrical halves 84, 85 of the winged initiation sections 52, 53, 54, 55 are connected together

5 by shear fasteners 81 and the two symmetrical halves 84, 85 are sealed by gasket 80. The gaskets 80 and the shear fasteners 81 are designed to keep the grout 56 from leaking into the interior of the winged initiation sections 52, 53, 54, 55 during the grout 56 placement. Furthermore, the gaskets 80 and shear fasteners 81 are  
10 designed to separate along the fracture plane 83 of the winged initiation sections 52, 53, 54, 55 during fracture initiation, as shown in FIG. 9, without physical damage to the two symmetrical halves 84, 85 of the winged initiation sections 52, 53, 54, 55. Any means of connecting the two symmetrical halves 84, 85 of the winged  
15 initiation sections 52, 53, 54, 55 can be made, including but not limited to clips, glue, or weakened fasteners, as long as the pressure keeping the two symmetrical halves 84, 85 together is greater than the pressure of the grout 56 on the exterior of the winged initiation sections 52, 53, 54, 55, i.e. the grout 56 is prevented from leaking  
20 into the interior of the winged initiation sections 52, 53, 54, 55. When the wall and or barrier geometry requires that the fractures be initiated and propagated from discrete soil zones 60 in the same injection casing 50, individual winged initiation sections 52, 53, 54, 55 or vertical cuts 8 in the injection casing 50 can be isolated with  
25 mechanical or inflatable packers 70, 71 prior to fracture initiation.

Referring to FIG. 7, two embodiments of the method are shown. In the first embodiment on the right, when the soil zone 60 surrounding the lower winged initiation section 55 requires that fracture initiation and propagation begin below upper winged  
30 initiation section 53, a single isolation packer 72 is set in injection casing 50 just above the winged initiation section 55. The fracture fluid 20 is pumped from the pumping/system operation 104, see FIG. 14, into the pressure pipe 59 and through the single isolation packer 72. As the fracture fluid 20 pressure increases below the



5 single isolation packer 72, the azimuth controlled vertical fracture is initiated and propagated as previously described. To initiate an azimuth controlled vertical fracture in the soil zone 60 around winged initiation section 52, upper and lower isolation packers 70, 71 are positioned in the injection casing 50 and set above and below  
10 the winged initiation section 52, as shown by the embodiment on the left. The upper isolation packer 70 is connected to lower isolation packer 71 by a perforated pipe 74. The bottom of the lower isolation packer 71 is plugged to prevent fracture fluid 20 from flowing through the lower isolation packer 71. With both  
15 isolation packers 70, 71 set, the fracture fluid 20 is pumped from the pumping/system operation 104, see FIG. 14, into a pressure pipe 59 through the upper isolation packer 70, and exits into the upper winged initiation section 52 from the perforations in the perforated pipe 74. As the pressure of the fracture fluid 20 increases between  
20 the set upper and lower isolation packers 70, 71, the azimuth controlled vertical fracture is initiated and propagated as previously described.

Referring to FIG. 9, as the pressure of the fracture fluid 20 is increased to a level which exceeds the lateral earth pressures, the  
25 two symmetrical halves 84, 85 of the winged initiation sections 84, 85 will begin to separate along the fracture plane 83 of the winged initiation sections 84, 85 during fracture initiation without physical damage to the two symmetrical halves 84, 85 of the winged initiation sections 84, 85. The gaskets 80 and shear fasteners 81  
30 fracture along the fracture plane 83 of the winged initiation sections 84, 85 during fracture initiation, as shown in FIG. 9, without physical damage to the two symmetrical halves 84, 85 of the winged initiation sections 84, 85. During separation of the two symmetrical halves 84, 85 of the winged initiation sections 84, 85,

5 the grout 56, which is bonded to the injection casing 50, see FIG. 7, and the two symmetrical halves 84, 85 of the winged initiation sections 84, 85 will begin to dilate the adjacent soil 60 forming a parting 89 of the soil 60 along the fracture plane 83 of the planned azimuth controlled vertical fracture. The fracture fluid 20 rapidly  
10 fills the parting 89 of the soil 60 by the initiated fracture. Within the two symmetrical halves 84, 85 of the winged initiation sections 84, 85, the fracture fluid 20 exerts normal forces 86 on the soil 60 perpendicular to the fracture plane 83 and opposite to the soil 60 horizontal stresses 87. Thus, the fracture fluid 20 progressively  
15 extends the parting 89 and continues to maintain the required azimuth of the initiated fracture. The azimuth controlled vertical fracture will be expanded by continuous pumping of the fracture fluid 20 until the desired geometry is achieved.

After initiation of the azimuth controlled vertical fracture and  
20 in order to determine when the fracture has achieved the desired in situ geometry, real time active resistivity tracking methods or a conventional tiltmeter tracking method can be employed. Referring to FIGs. 10, 11, and 12, a real time active resistivity tracking method and apparatus is shown. In FIG. 10, an individual injection  
25 casing 91 is shown in a top plan view. In most applications multiple injection casings 91 would be required to employ a real time tracking method. Generally, vertical arrays 90 of resistivity receivers 115, 121, 127, 133, as shown in FIG. 12, are located parallel to fracture plane 92 of the planned azimuth controlled  
30 vertical fracture, but offset on either one or both sides are the locations of the vertical arrays 90 of resistivity receivers 115, 121, 127, 133.

Referring to FIG. 11, six resistivity receiver arrays 90 are illustrated in a sectional view from FIG. 10. Each array 90

5 comprises a plurality of individual receivers **110-133** vertically connected as shown in FIG. 12 and spaced at depths parallel to the bore hole **105**. The injection casing **91** along with the winged initiation section **107** is shown offset and parallel to the connecting plane **92** of the vertical resistivity arrays **90** for clarity. As shown in  
10 FIG. 12, the insulated conductors **201, 202, 203, 204** for each individual resistivity receiver **115, 121, 127, 133** are connected to a data acquisition system **102** seen in FIG. 11. The data acquisition system **102** is comprised of a multi-channel electronic switching system (multiplexer), an analog to digital converter (A to D), and a  
15 storage device that stores the incoming data. The data acquisition system **102** is coupled to a computer **103** where incoming data is analyzed by an installed software program.

Referring to FIG. 12, the vertical array **90** of resistivity receivers **115, 121, 127, 133** is installed in conventional bore holes  
20 **211**. Typically, the vertical array **90** of resistivity receivers **115, 121, 127, 133** is constructed of a plurality of individual resistivity receivers **115, 121, 127, 133**. Each resistivity receiver **115, 121, 127, 133** is manufactured from an electrically conductive metal, usually copper, and each resistivity receiver **115, 121, 127, 133** is  
25 attached to an insulated conductor **201, 202, 203, 204** which are routed through a nonconductive pipe or tubing **95** to the ground surface **93**. The individual resistivity receivers **115, 121, 127, 133** are spaced as required and attached to the nonconductive pipe or tubing **95**. The annular space between the bore hole **211** and the  
30 vertical array **90** of resistivity receivers **115, 121, 127, 133** is backfilled with clean sand **212** to a level above the uppermost individual resistivity receiver **115**. The remainder of the bore hole **211** is backfilled with a surface seal **210** comprising bentonite clay or a non-shrink or low shrink cement based grout.

5           Using influence functions such as Green's functions, the computer software program can relate incremental measurements of the earth's induced voltage to the geometry change of an electrically energized initiated fracture. A series of sequential incremental solutions from the influence functions can be used to  
10       create an inverse model. The geometry of the fracture can be calculated during the injection process by solving the series of influence functions incorporated into the inverse model. Utilizing measured induced voltages from electrifying the fracture fluid 20, the user can monitor the injected flow of the fracture fluid 20 to  
15       determine and control the in situ geometry of the fracture during the injection process.

          The computer 103 displays an image of the initiated and propagating fracture in real time. Control of the pumping system/operation 104 can be accomplished by data input from the  
20       computer 103.

          To generate the data, a high frequency low voltage electrical supply 134 is attached to the injection casing 91 which can be either electrically conductive or connected to an electrically conductive electrode. The electrically conductive electrode can be placed inside  
25       the injection casing 91 so that the fracture fluid 20 when pumped into the injection casing 91 by the pumping system/operation 104 will receive and conduct the electrical voltage. That is, the fracture fluid 20 will become energized by the electrical voltage. A reference ground electrode 109 is driven into the ground surface 93  
30       as far as practical from the vertical arrays 90 and the individual resistivity receivers 110-133. The reference ground can be, without limitation, a subsurface electrode or a neighboring initiated fracture. Before the azimuth controlled vertical fracture is initiated, the injection casing 91 is electrified. The voltages from the injection

5 casing 91 to the reference ground electrode 109, and from the resistivity receivers 110-133 to the reference ground electrode 109 are measured, stored, and displayed by the data acquisition system 102 and computer and integrated software 103. The measured voltages are then used as background.

10 Referring to FIGs. 15 and 16, a visual display showing the locations of the individual resistivity receivers 200 within a ground formation is illustrated. In FIG. 16, two bore holes 205, 210 are shown within the arrangement of the individual resistivity receivers 200. The voltages of the individual resistivity receivers 200 are  
15 measured against the background reference voltages, and a visual display of a propagating azimuth controlled vertical fracture in the subsurface is shown.

Finally, it will be understood that the preferred embodiment has been disclosed by way of example, and that other modifications  
20 may occur to those skilled in the art without departing from the scope and spirit of the appended claims.

5

## CLAIMS

What is claimed is:

1. A method for creating vertical fractures oriented at a predetermined azimuth in a formation of unconsolidated and weakly cemented soil and sediments, comprising:

10 drilling a bore hole with an axis in the formation to a predetermined depth;

installing an injection casing with an outer surface in the bore hole at the predetermined depth, wherein an annular space exists between the outer surface of the casing and the bore hole;

15 filling the annular space with a grout that bonds to the outer surface of the casing;

weakening the injection casing along a vertical weakening line lying within a fracture plane, which fracture plane extends from the axis of the bore hole radially along the  
20 predetermined azimuth; and

injecting a fracture fluid into the injection casing with a sufficient fracturing pressure to dilate the injection casing, the grout, and the formation and thereby initiate a vertical fracture in the formation at the weakening line.

5

2. The method of Claim 1, wherein the installation of the injection casing comprises the following step:

installing an initiation section of the injection casing at a predetermined depth in the bore hole, wherein the initiation section  
10 is weakened along the weakening line so that the initiation section separates under the fracturing pressure, whereby the fracture fluid dilates the grout and the formation to initiate the fracture in the formation at the weakening line.

15 3. The method of Claim 1, wherein the fracture fluid does not leak off into the formation from the fracture.

4. The method of Claim 1, wherein the fracture fluid comprises a proppant, and the fracture fluid is able to carry the  
20 proppant of the fracture fluid at low flow velocities.

5. The method Claim 1, wherein the fracture fluid is clean breaking with minimal residue.

25 6. The method of Claim 1, wherein the fracture fluid has a low friction coefficient.

7. The method of Claim 1, wherein the fracture fluid comprises:  
30 a water based guar gum gel and a bentonite cement slurry.

8. The method of Claim 1, wherein the fracture fluid comprises a proppant to create a containment wall contained within the vertical fracture.

5

9. The method of Claim 1, wherein the fracture fluid comprises a proppant to create a treatment barrier contained within the vertical fracture.

10

10. The method of Claim 1, wherein a plurality of bore holes with injection casings therein are used to create a plurality of vertical fractures that interconnect.

15

11. The method of Claim 10, wherein the fracture fluid comprises a proppant for creating a continuous containment wall contained within the interconnected plurality of vertical fractures.

20

12. The method of Claim 10, wherein the fracture fluid comprises a proppant for creating a continuous treatment barrier contained within the interconnected plurality of vertical fractures.

25

13. The method of Claim 1, wherein the injection of the fracture fluid is controlled based upon a sequential incremental solution to determine incremental fracture geometry changes as the fracture is propagating and based on the measured conductivity of the fracture fluid.



5        14.        A method for tracking a propagating vertical fracture  
in a formation of unconsolidated and weakly cemented soil and  
sediments comprising:

drilling a bore hole with an axis in the formation to a  
predetermined depth;

10                installing an injection casing with an outer surface in  
the bore hole at the predetermined depth;

installing resistivity arrays, comprising a plurality of  
individual resistivity receivers, at a predetermined set of depths  
within the formation and within the bore hole;

15                injecting a fracture fluid into the bore hole;

electrifying the fracture fluid;

initiating a vertical fracture in the injection casing and  
the formation, wherein the fracture fluid initiates and propagates the  
vertical fracture; and

20                regulating the injection of the fracture fluid as the  
fracture is propagating using a sequential incremental solution to  
determine incremental fracture geometry changes based on the  
measured conductivity and induced voltages in the earth due to the  
propagating fracture fluid.

25                15.        The method of Claim 14, wherein the fracture fluid is  
at least twenty times more conductive than the formation being  
fractured.

30                16.        The method of Claim 14, wherein the fracture fluid  
does not leak off into the formation.

5        17.        The method of Claim 14, wherein the fracture fluid  
comprises a proppant, and the fracture fluid is able to carry the  
proppant of the fracture fluid at low flow velocities.

18.        The method Claim 14, wherein the fracture fluid is  
10    clean breaking with minimal residue.

19.        The method of Claim 14, wherein the fracture fluid has  
a low friction coefficient.

15        20.        The method of Claim 14, wherein the fracture fluid  
comprises:  
a water based guar gum gel and a bentonite cement  
slurry.

5        21.     An apparatus for tracking a propagating vertical fracture in a formation of unconsolidated and weakly cemented soil and sediments comprising:

             a fracture fluid more conductive than the formation;  
             an electrical power supply to energize the fracture  
10    fluid;

             a plurality of electrical resistivity receivers spaced throughout the formation;

             a reference electrode capable of measuring the resistivity of the formation; and

15        a monitoring system capable of measuring data collected from the resistivity receivers and the reference electrode.

             22.     The apparatus of Claim 20, wherein the fracture fluid is twenty times more conductive than the formation.

20        23.     The method of Claim 20, wherein the fracture fluid does not leak off into the formation.

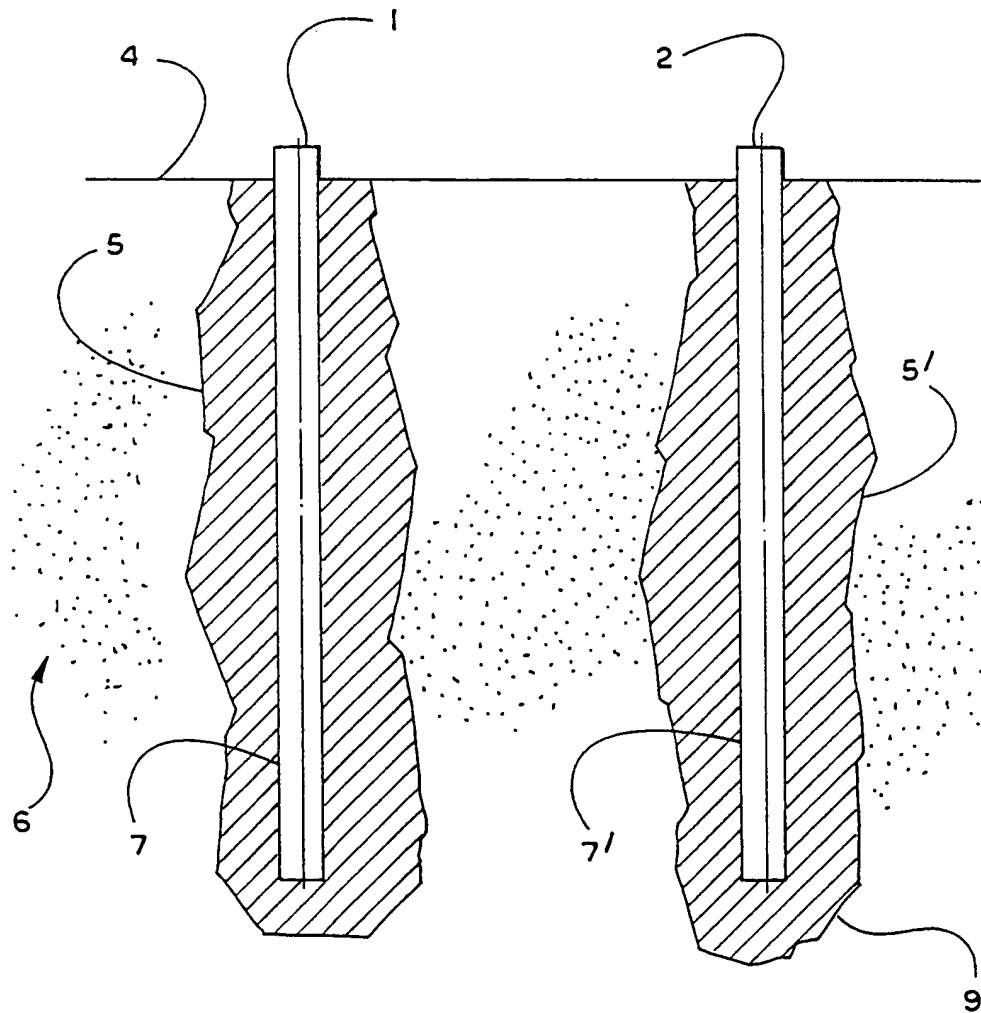
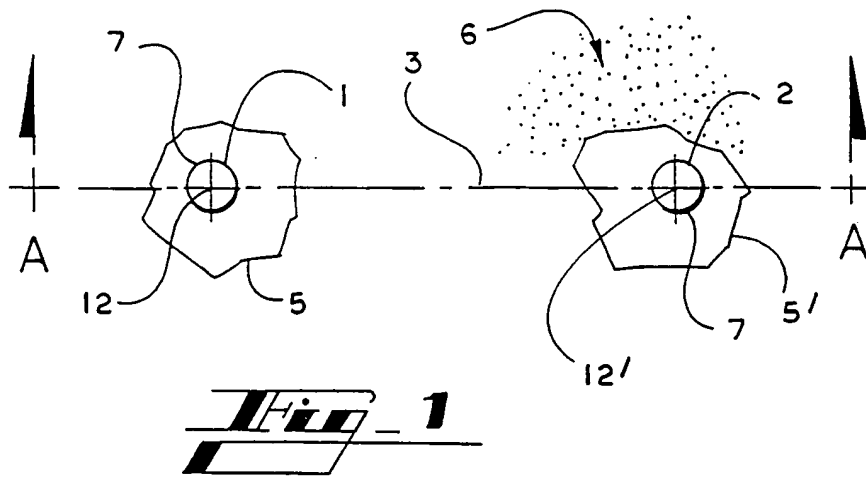
             24.     The method of Claim 20, wherein the fracture fluid  
25    comprises a proppant, and the fracture fluid is able to carry the proppant of the fracture fluid at low flow velocities.

             25.     The method Claim 20, wherein the fracture fluid is clean breaking with minimal residue.

30        26.     The method of Claim 20, wherein the fracture fluid has a low friction coefficient.

- 5           27.     The method of Claim 20, wherein the fracture fluid  
              comprises:  
                      a water based guar gum gel and a bentonite cement  
              slurry.

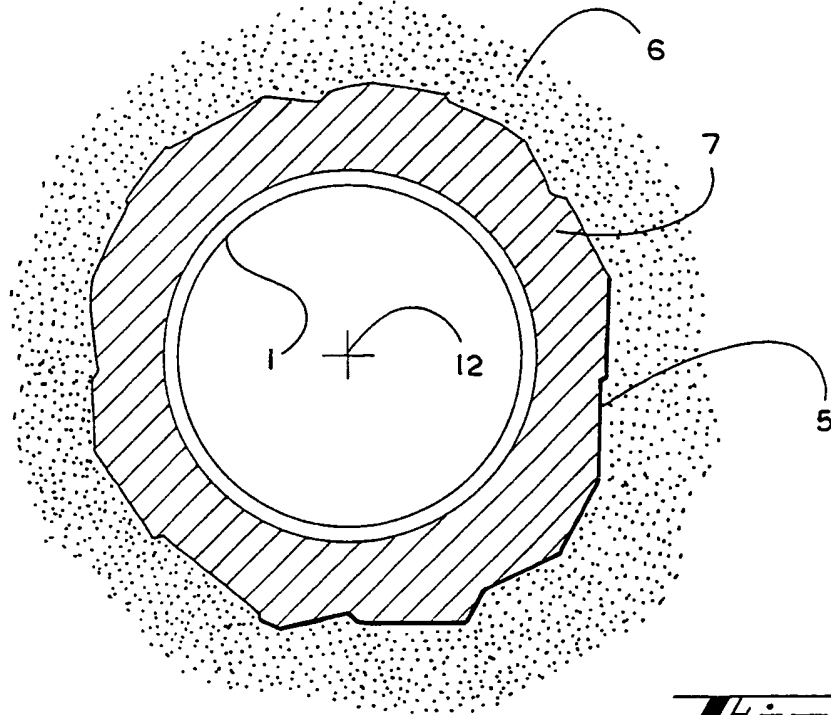
10



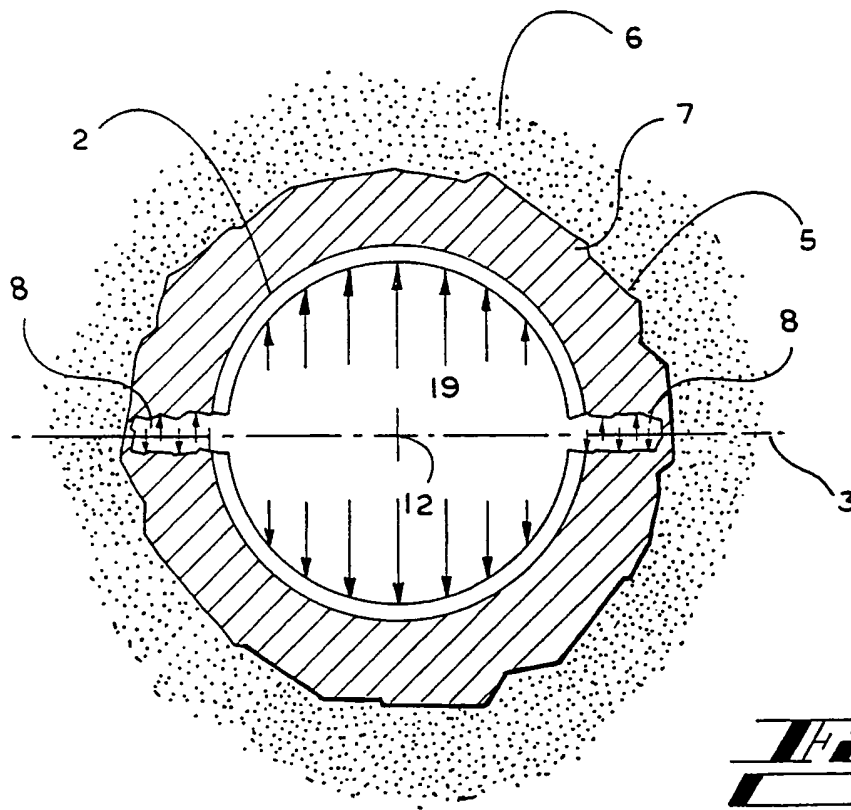
SECTION A - A

**Fig. 2**

SUBSTITUTE SHEET (RULE 26)

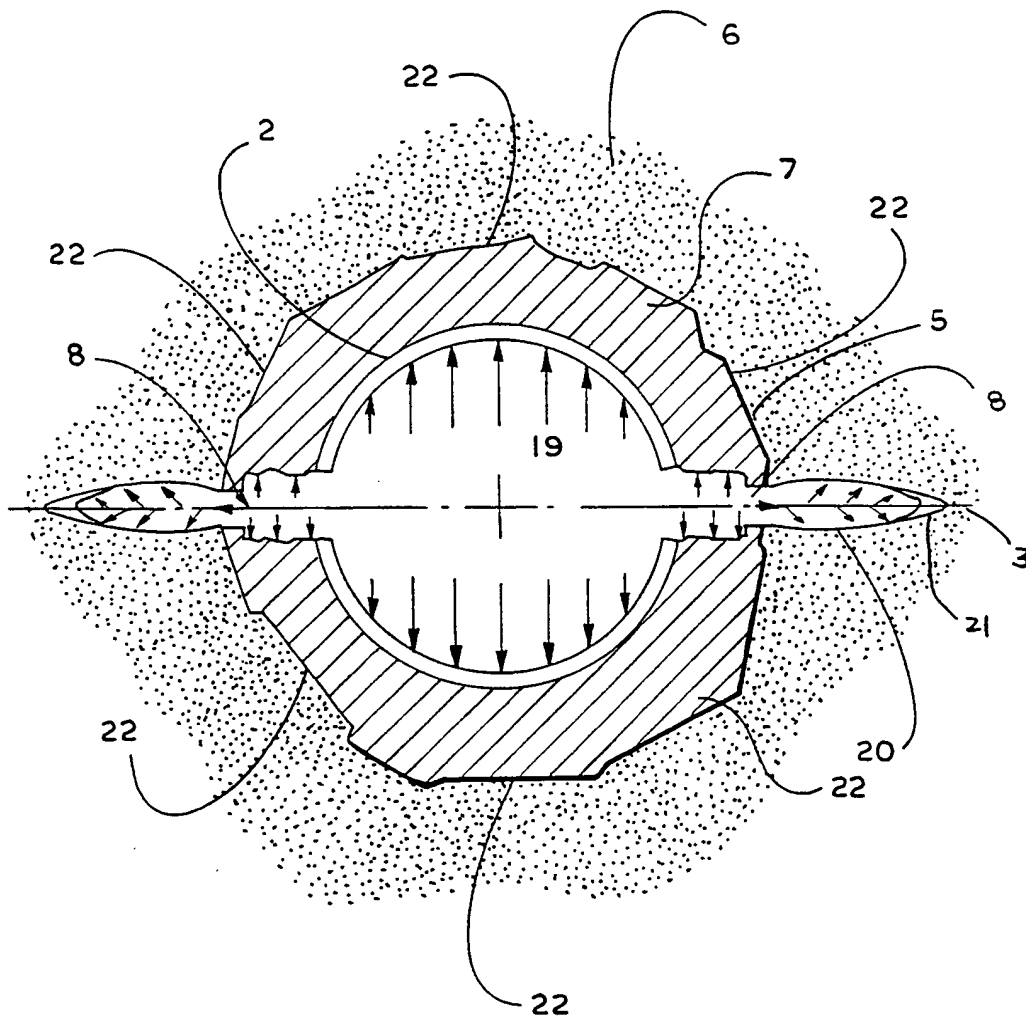


**Fig. 3**

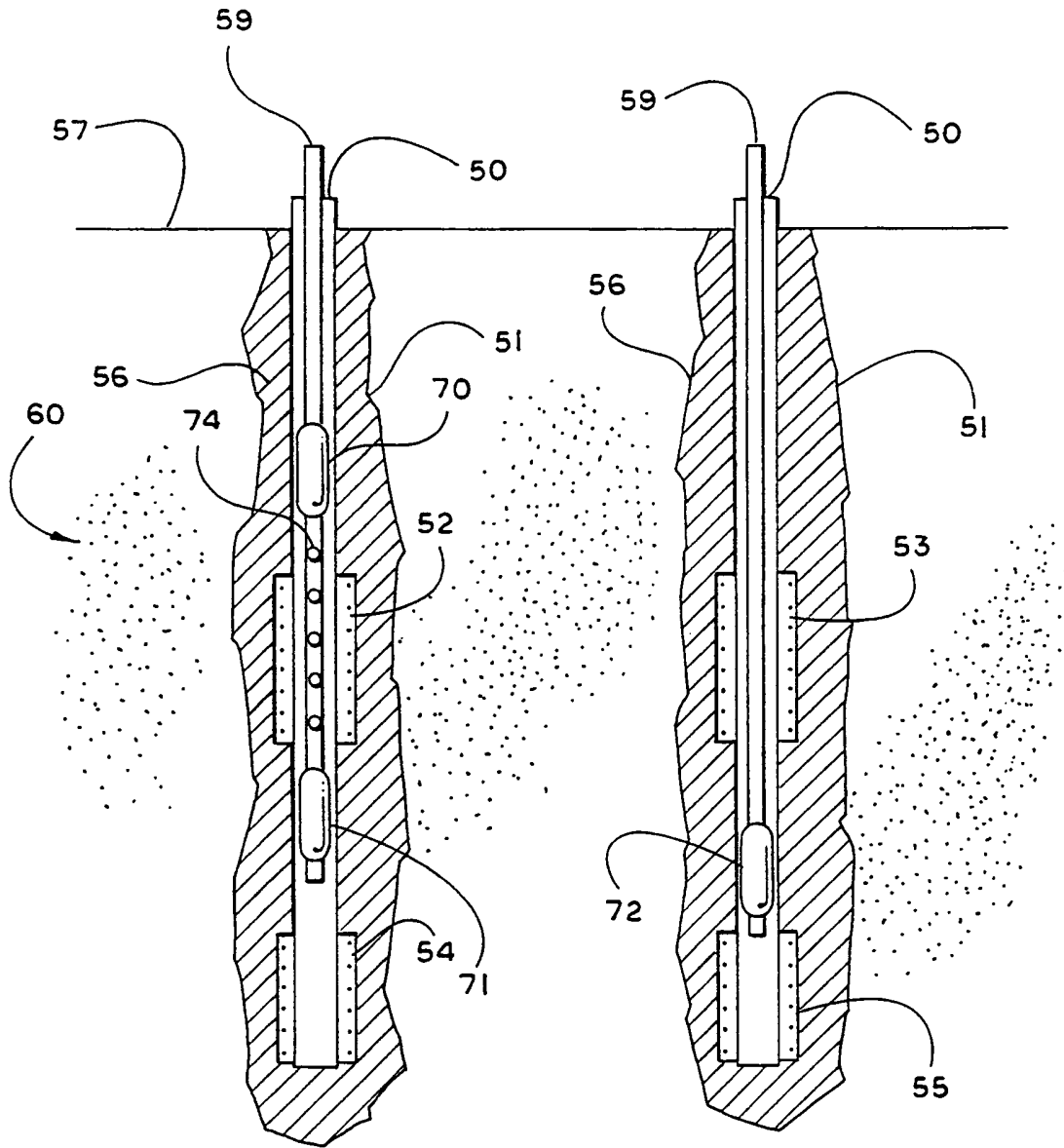


**Fig. 4**

SUBSTITUTE SHEET (RULE 26)



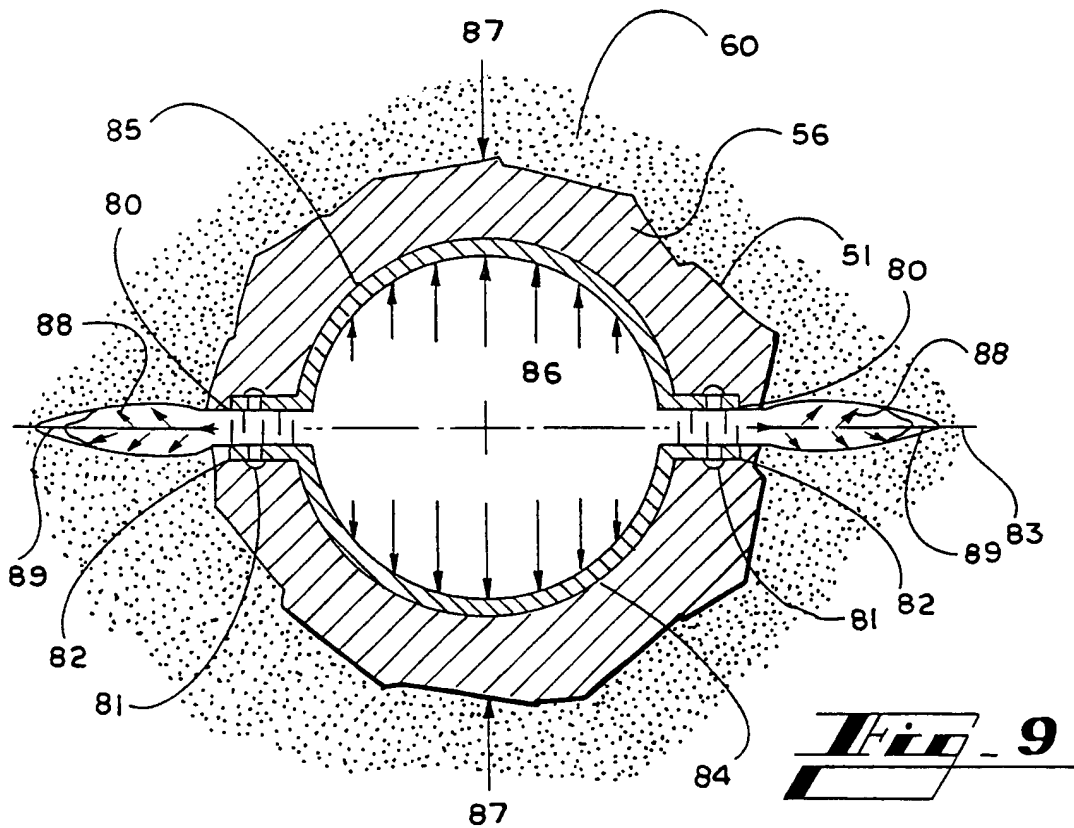
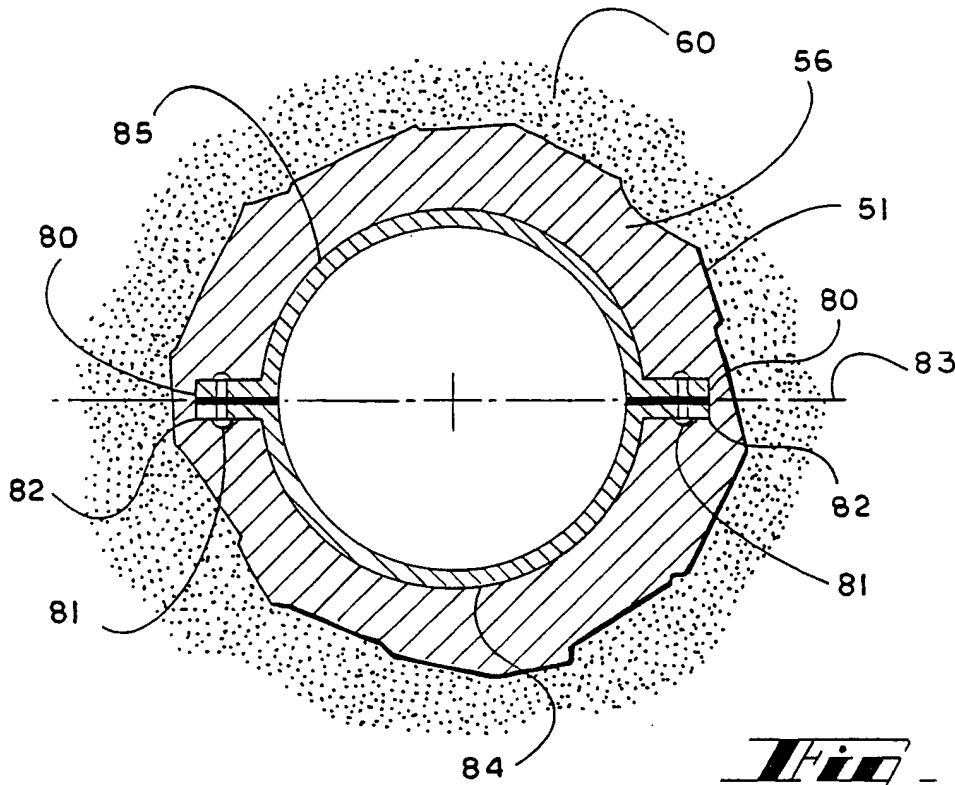
**Fig. 6**

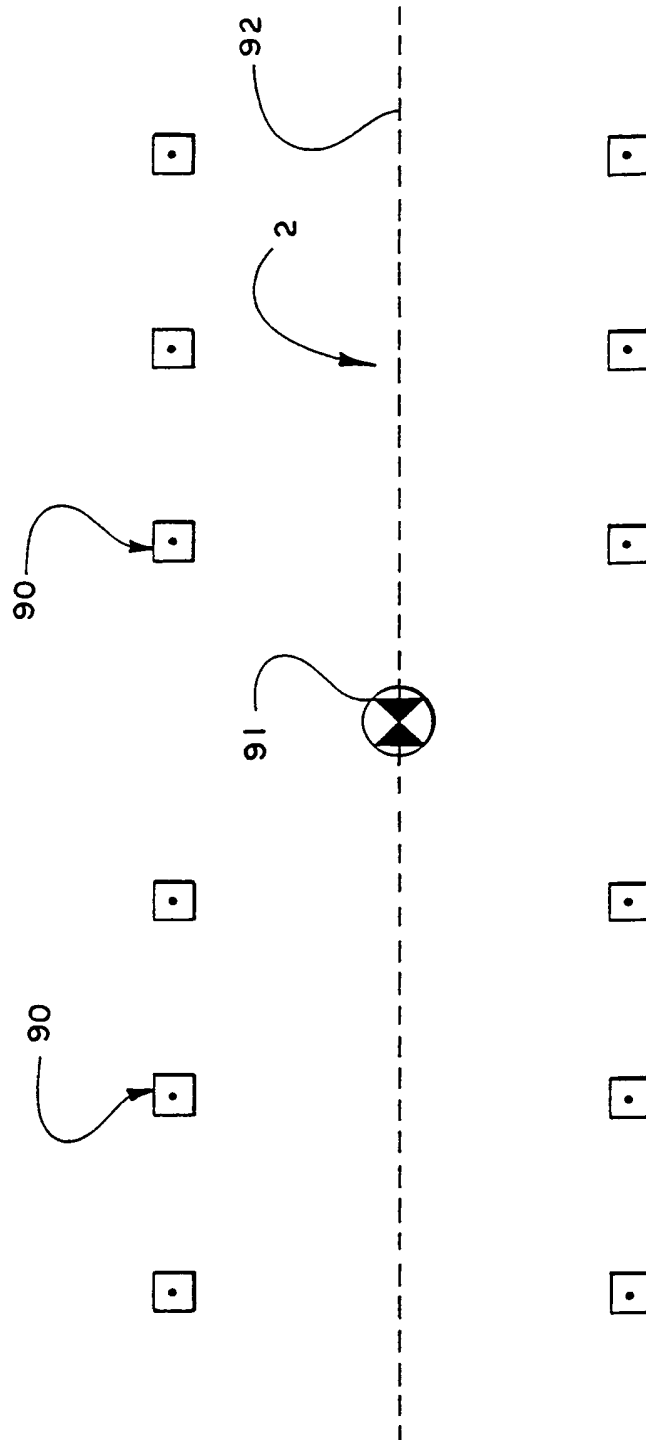


**Fig. 7**

**SUBSTITUTE SHEET (RULE 26)**

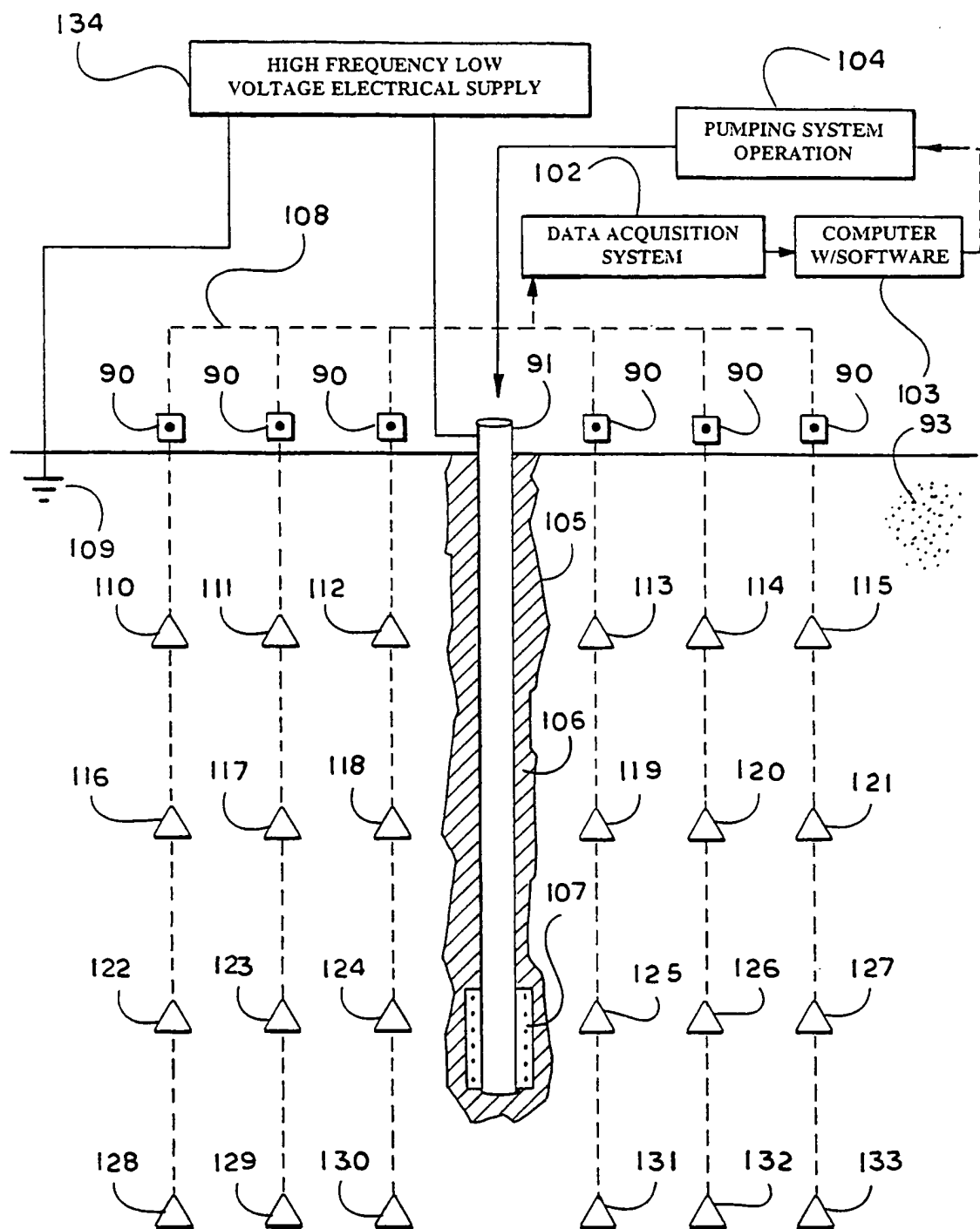




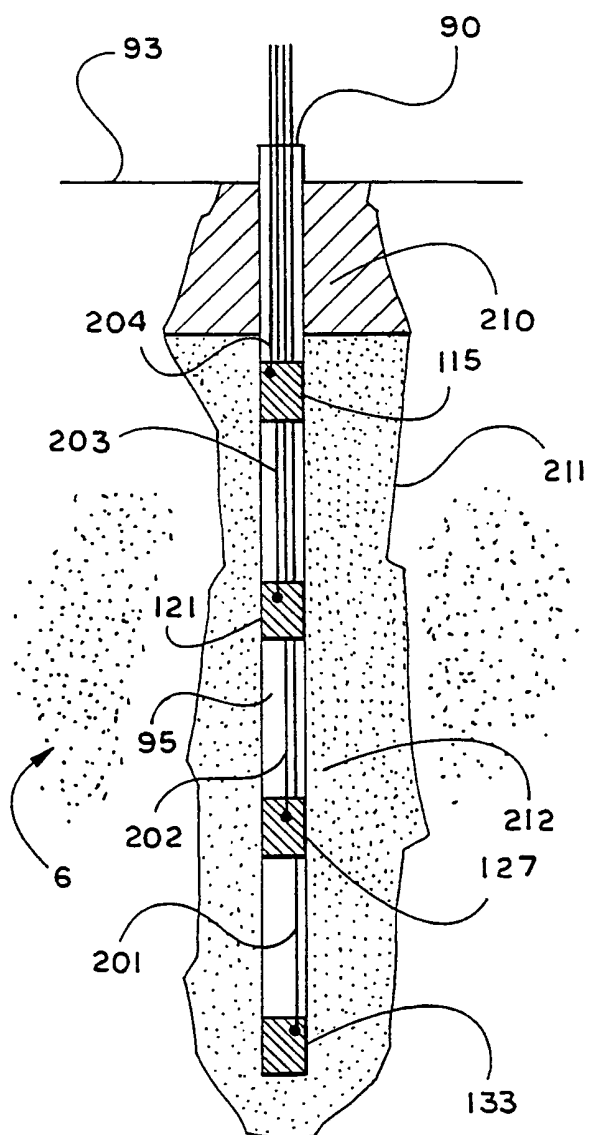
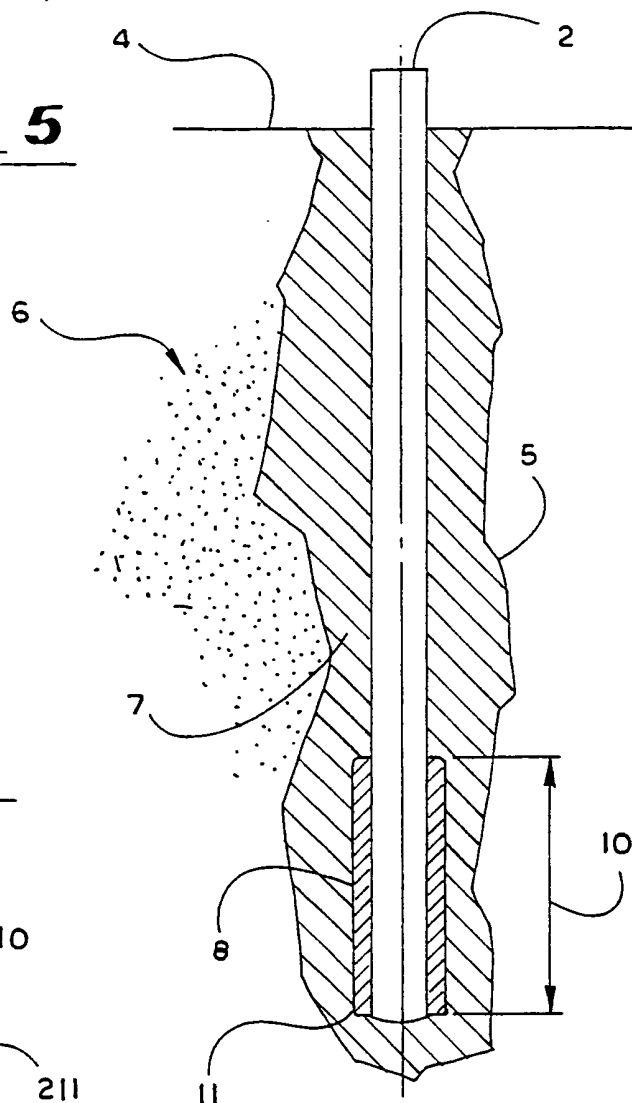


***Fig. 10***

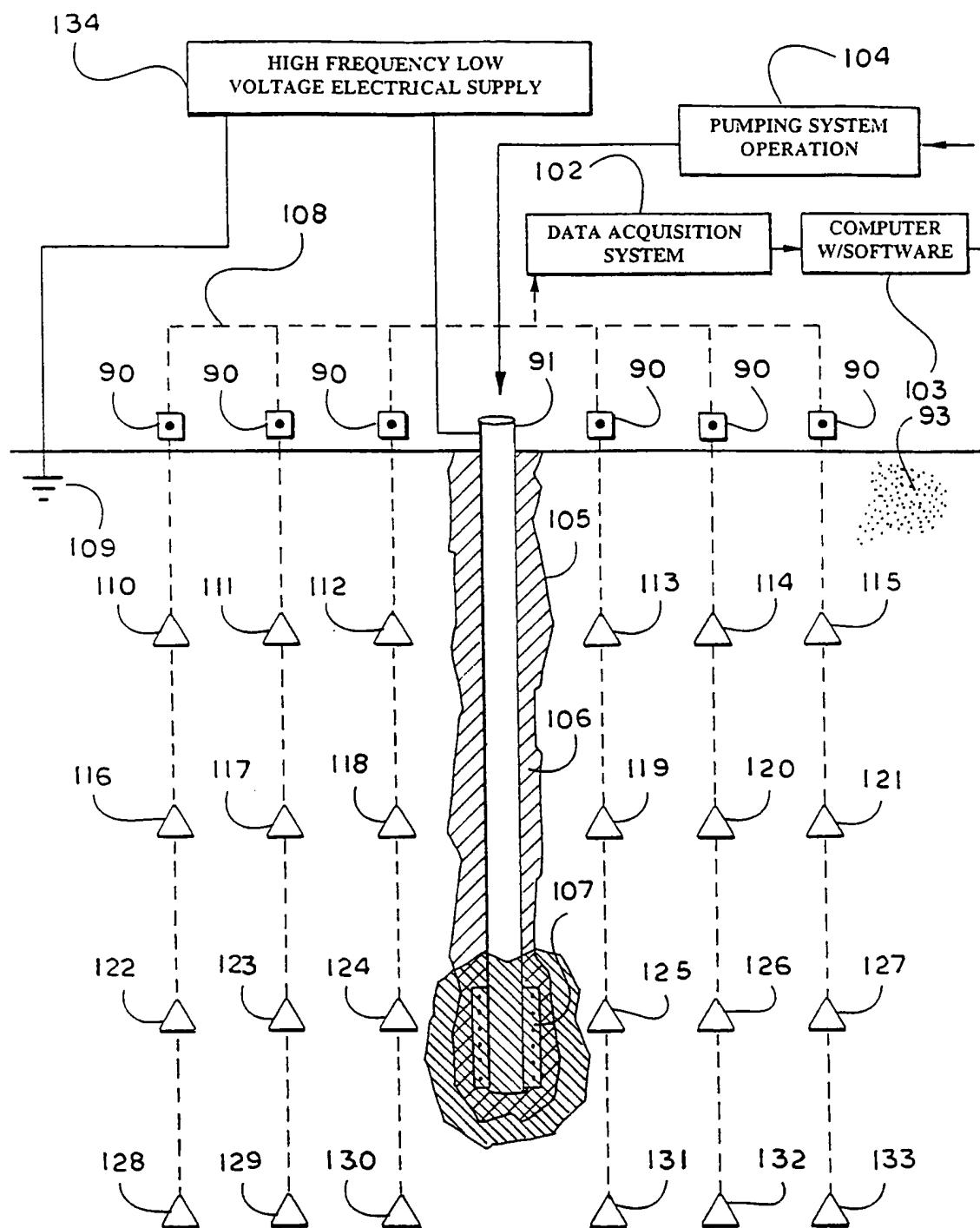
SUBSTITUTE SHEET (RULE 26)

**Fig. 11**

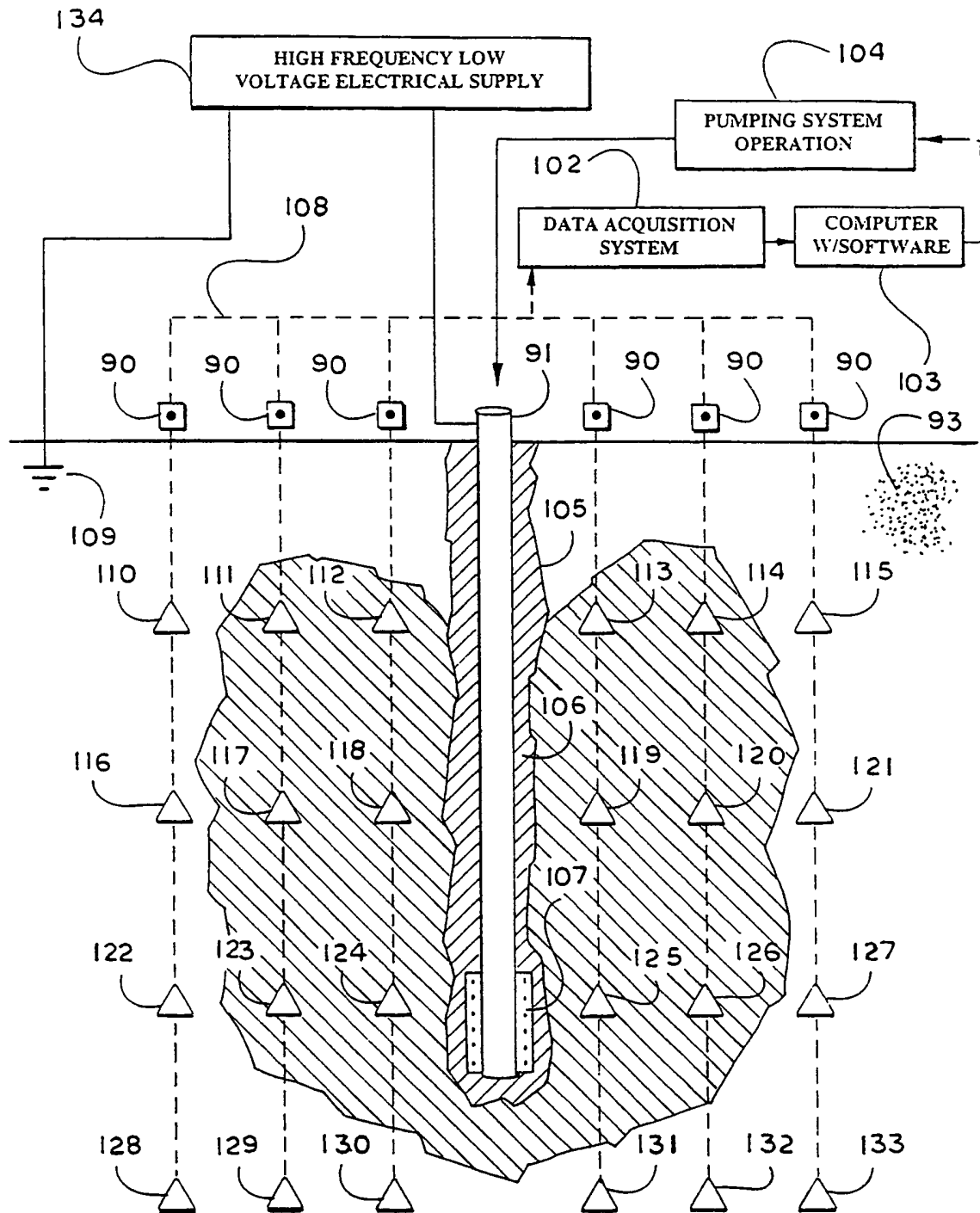
SUBSTITUTE SHEET (RULE 26)



**SUBSTITUTE SHEET (RULE 26)**

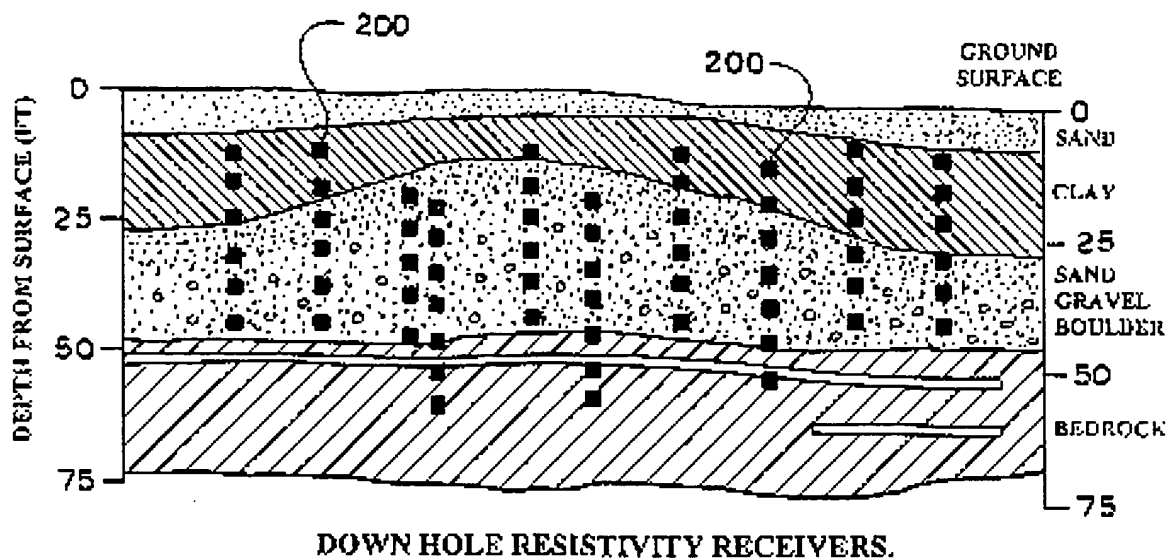


**Fig. 13**

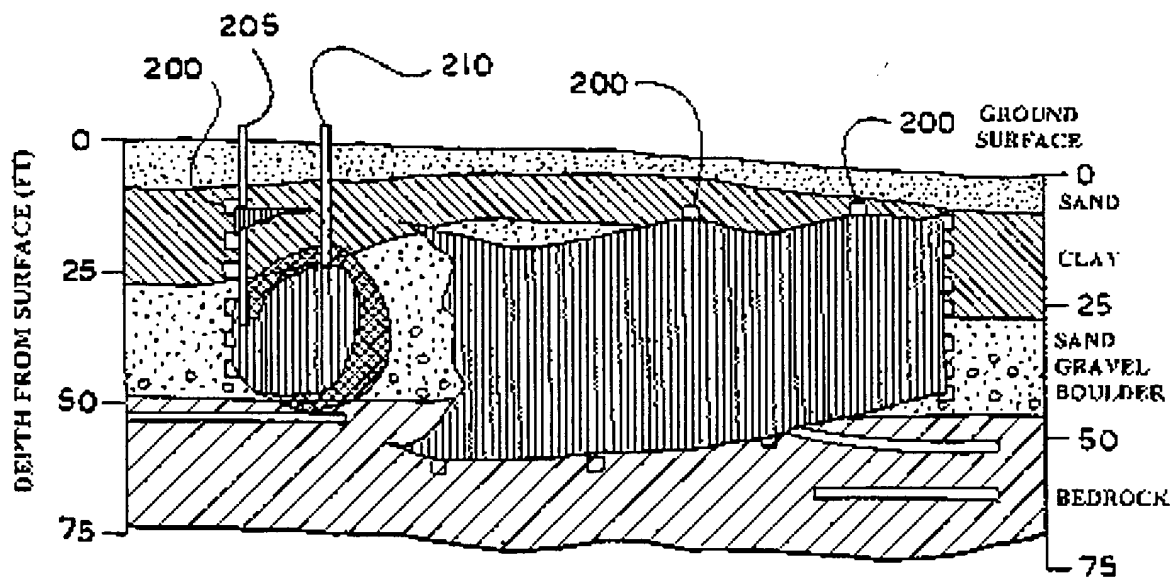


**Fig. 14**

SUBSTITUTE SHEET (RULE 26)



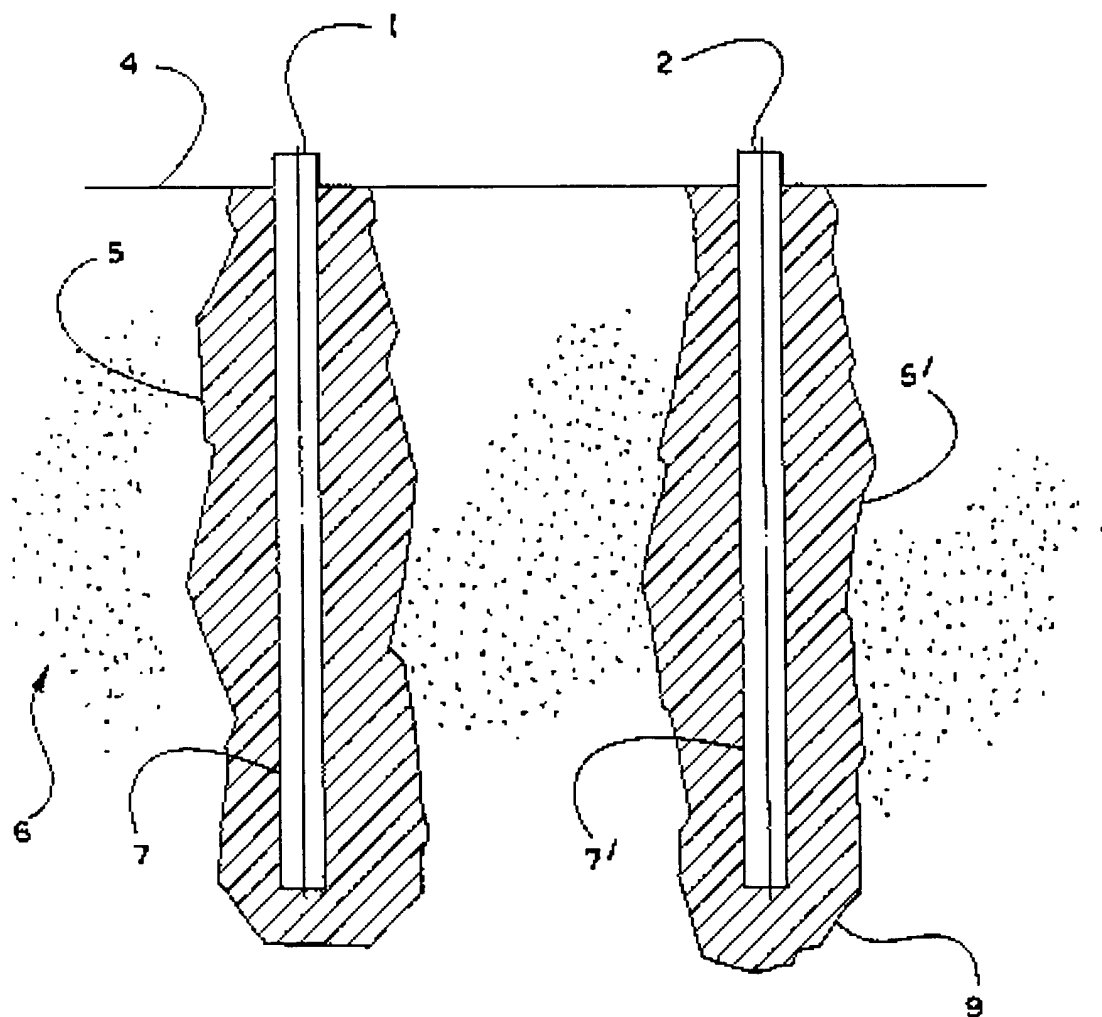
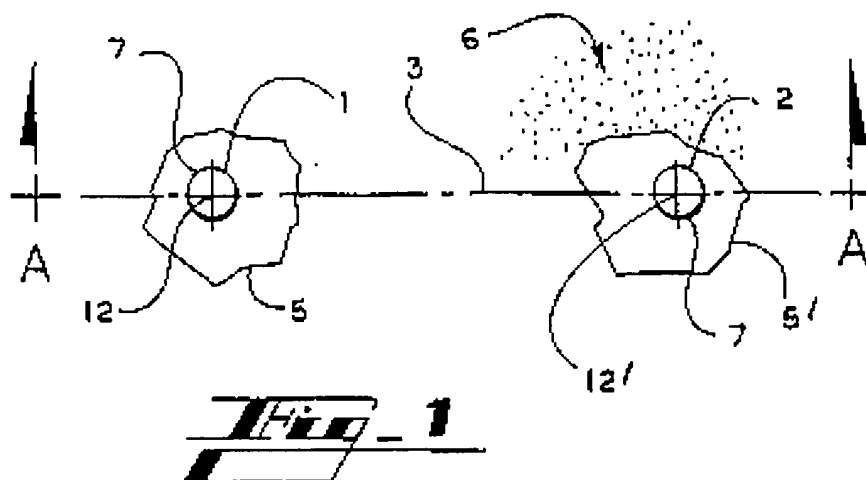
**Fig. 15**



**Fig. 16**

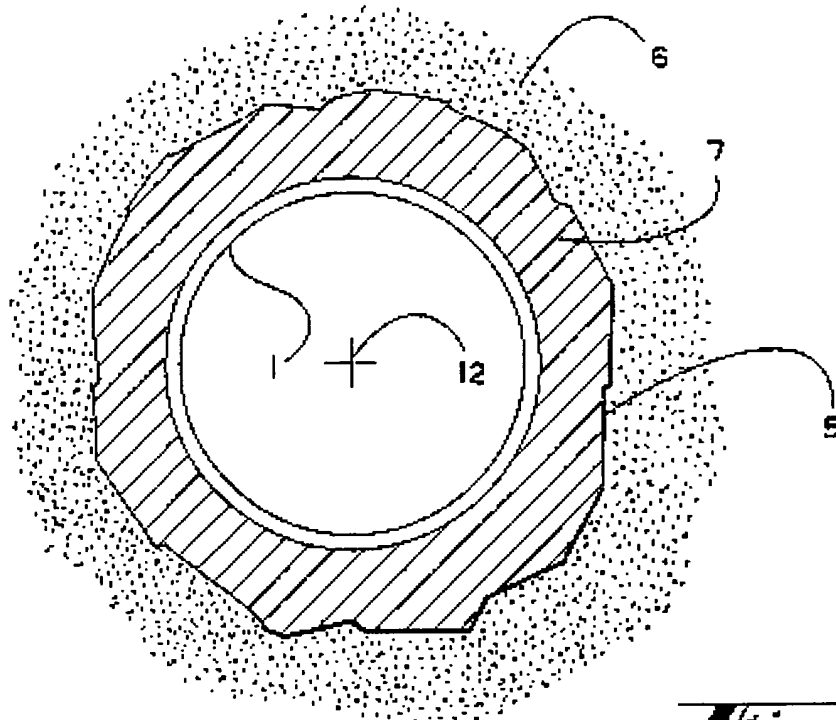
**THIS PAGE BLANK (USPTO)**



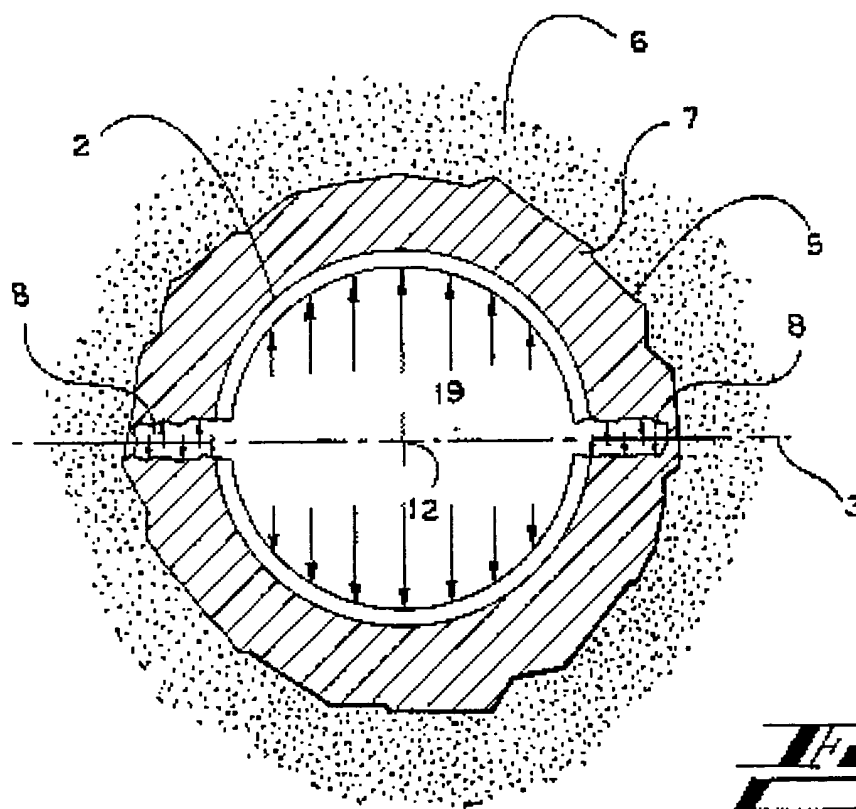


SECTION A-A

SUBSTITUTE SHEET (RULE 26)

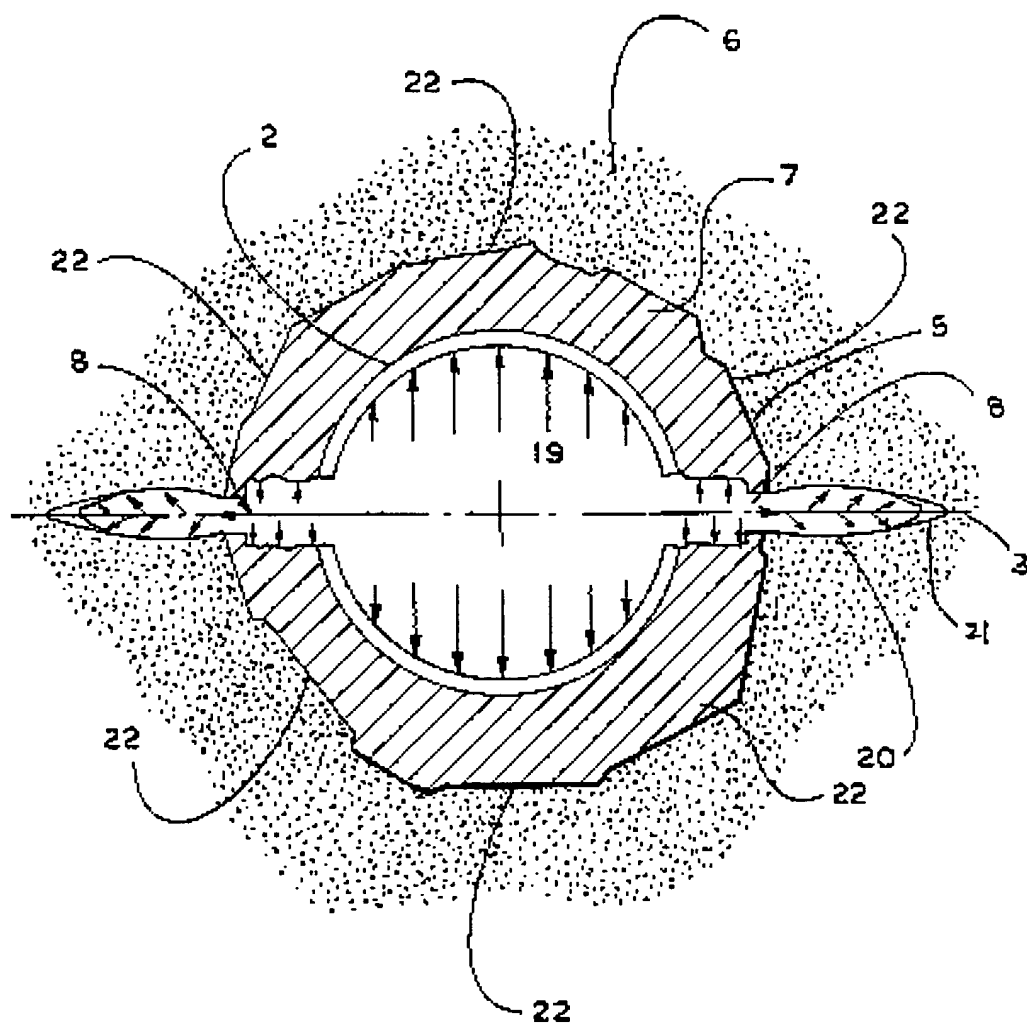


***Fig. 3***



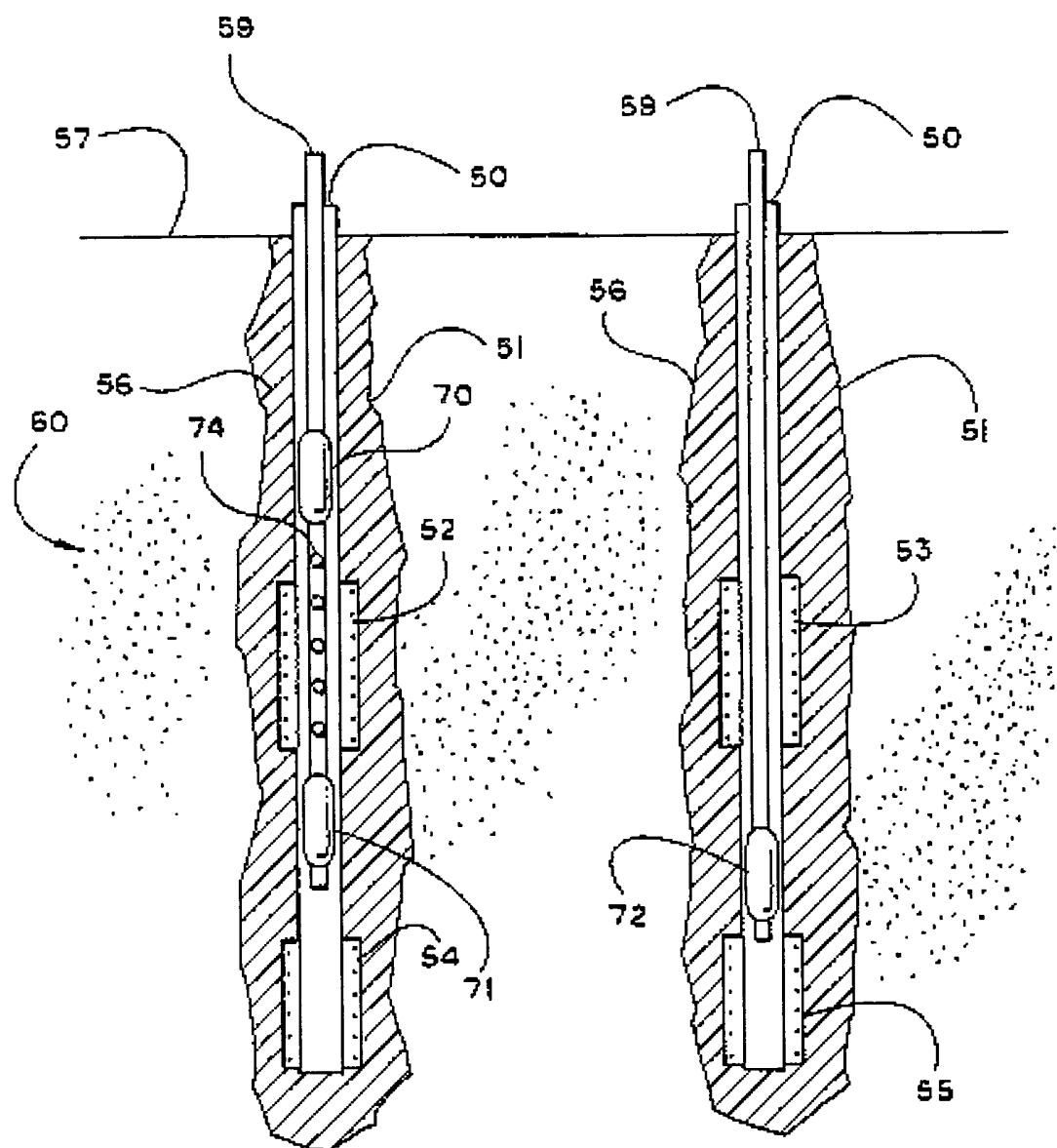
***Fig. 4***

SUBSTITUTE SHEET (RULE 26)



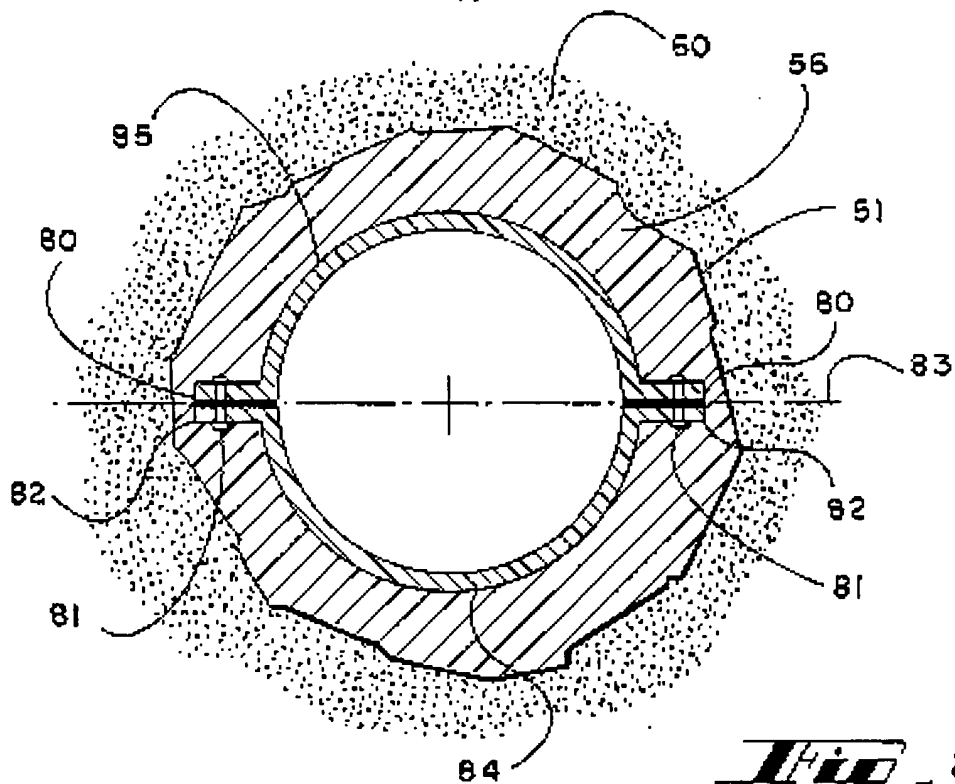
***Fig. 6***

SUBSTITUTE SHEET (RULE 26)

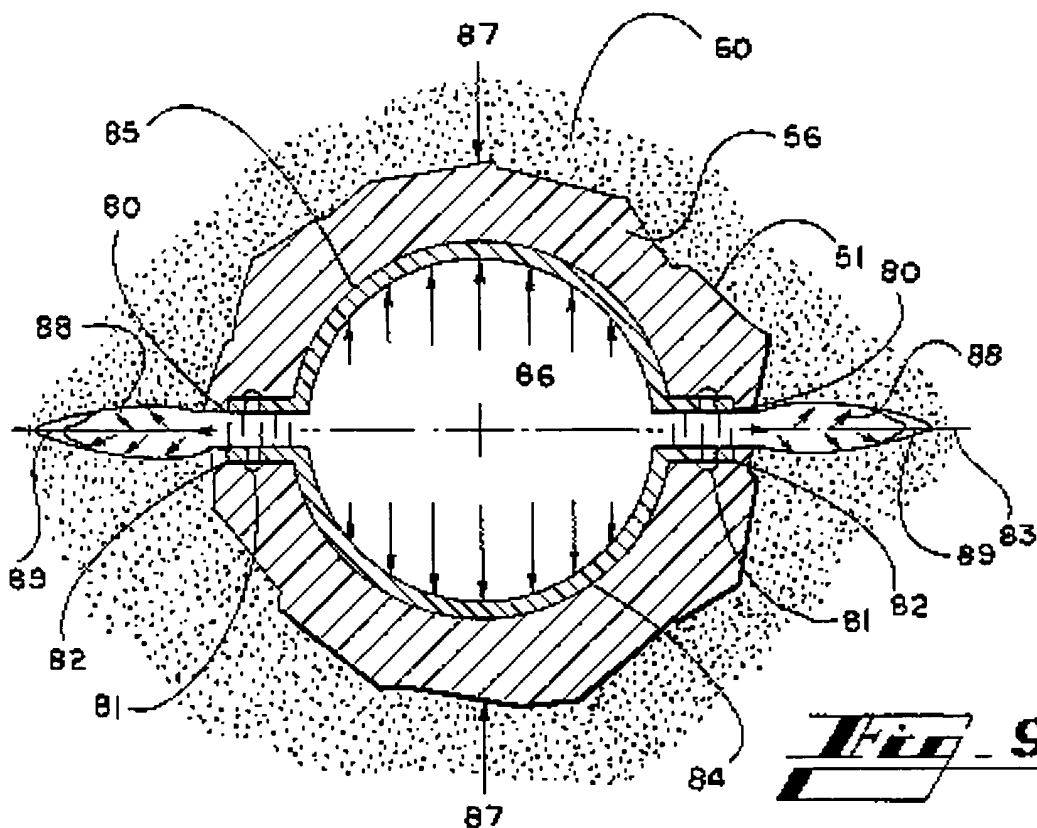


**Fig. 7**

**SUBSTITUTE SHEET (RULE 26)**

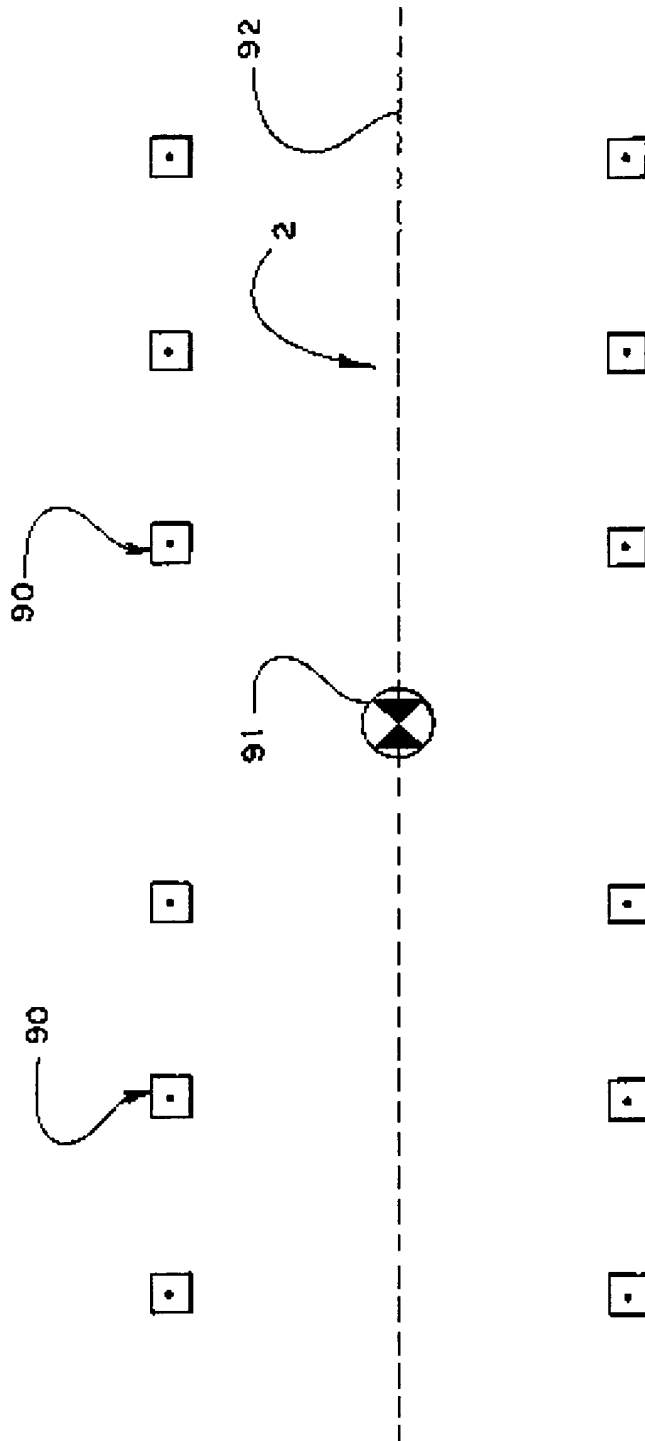


**FIG. 8**



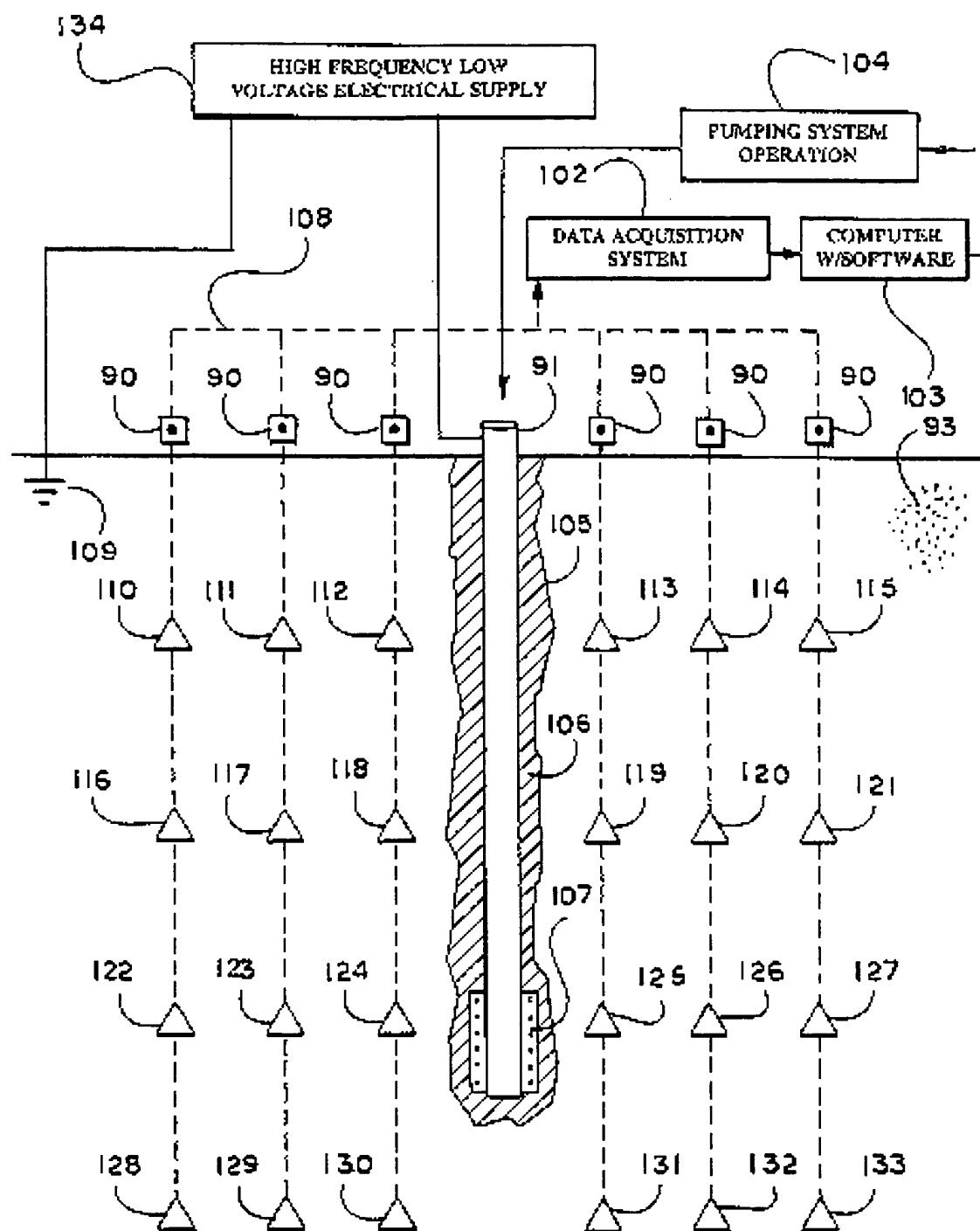
**FIG. 9**

SUBSTITUTE SHEET (RULE 26)



**Fig. 10**

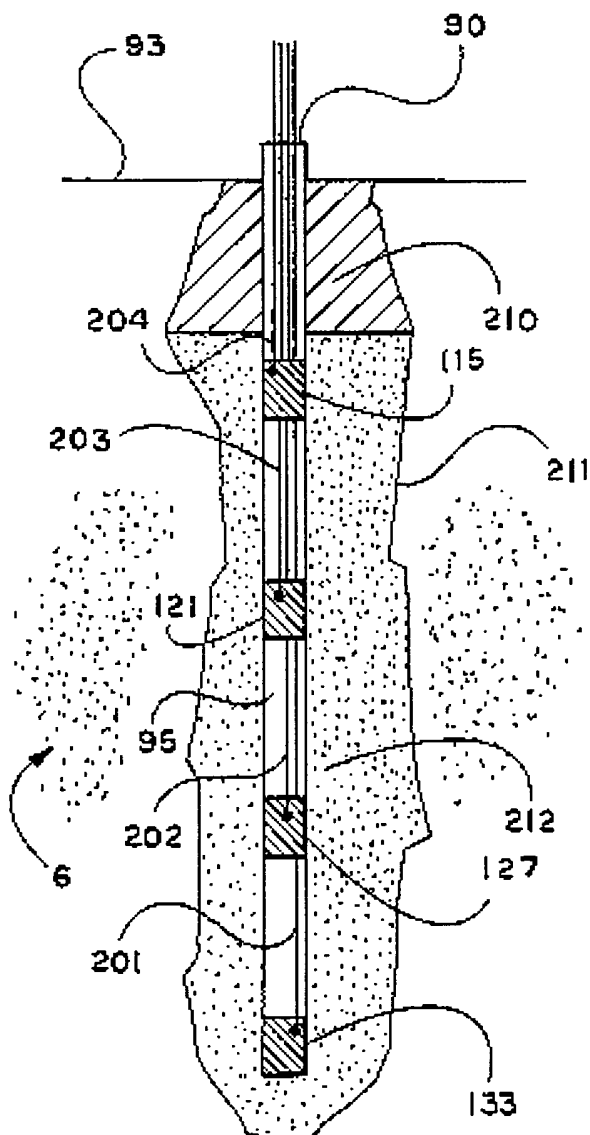
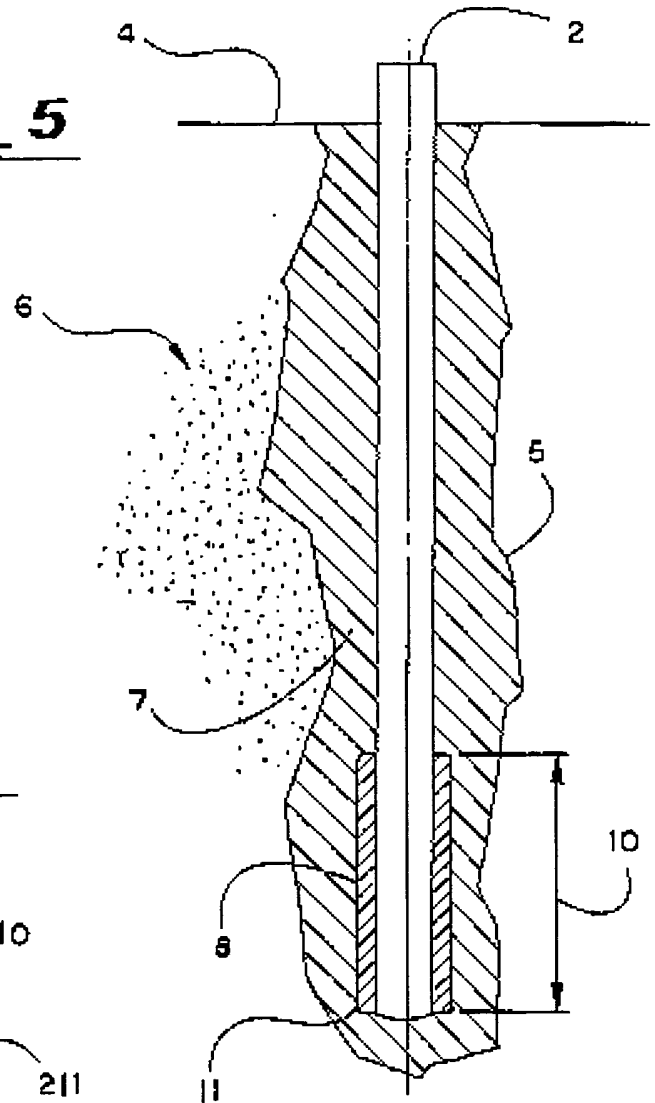
SUBSTITUTE SHEET (RULE 26)



SUBSTITUTE SHEET (RULE 25)

8/11

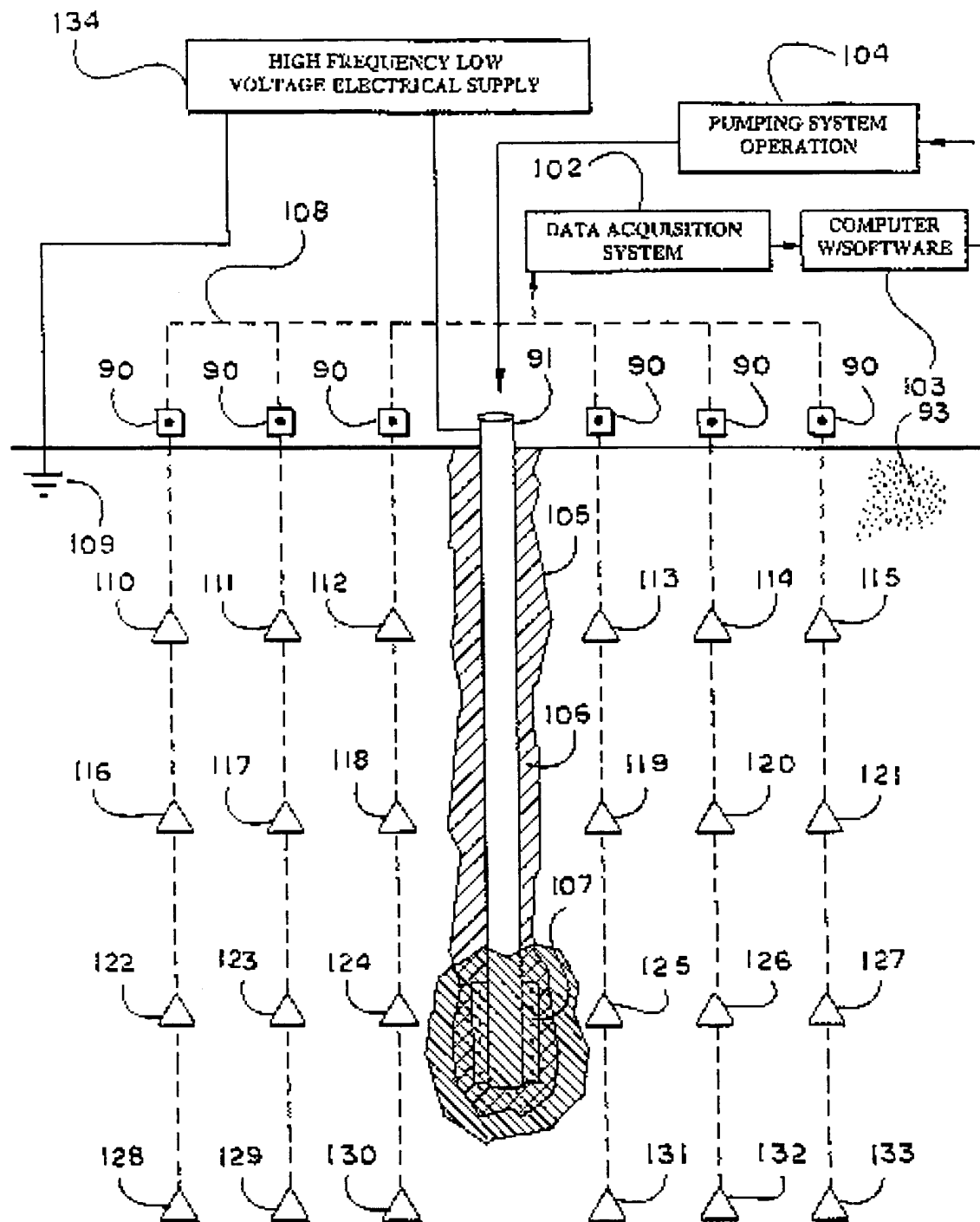
**Fig. 5**



**Fig. 12**

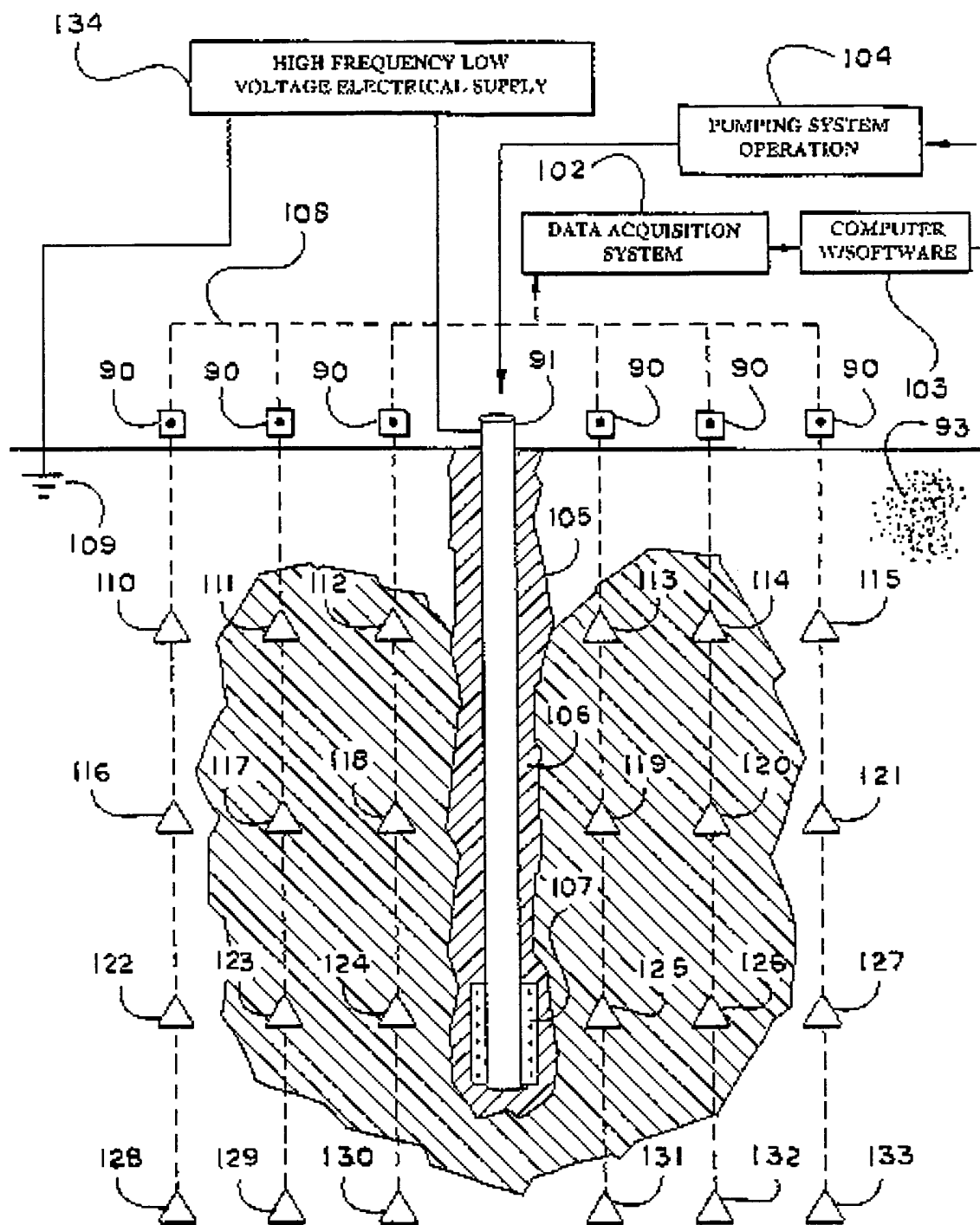
SUBSTITUTE SHEET (RULE 26)





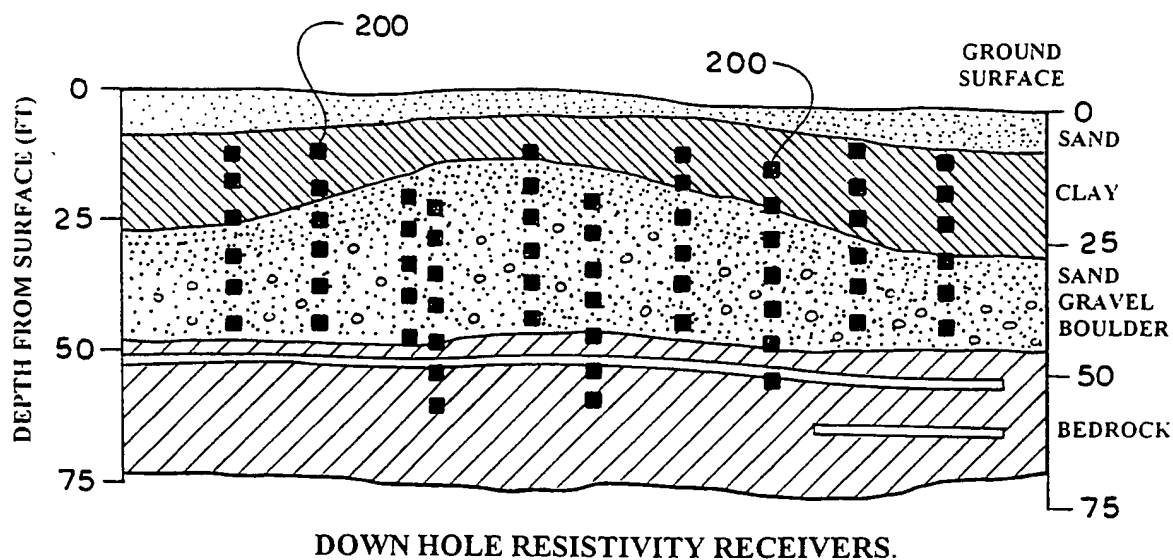
**Fig. 13**

SUBSTITUTE SHEET (RULE 26)

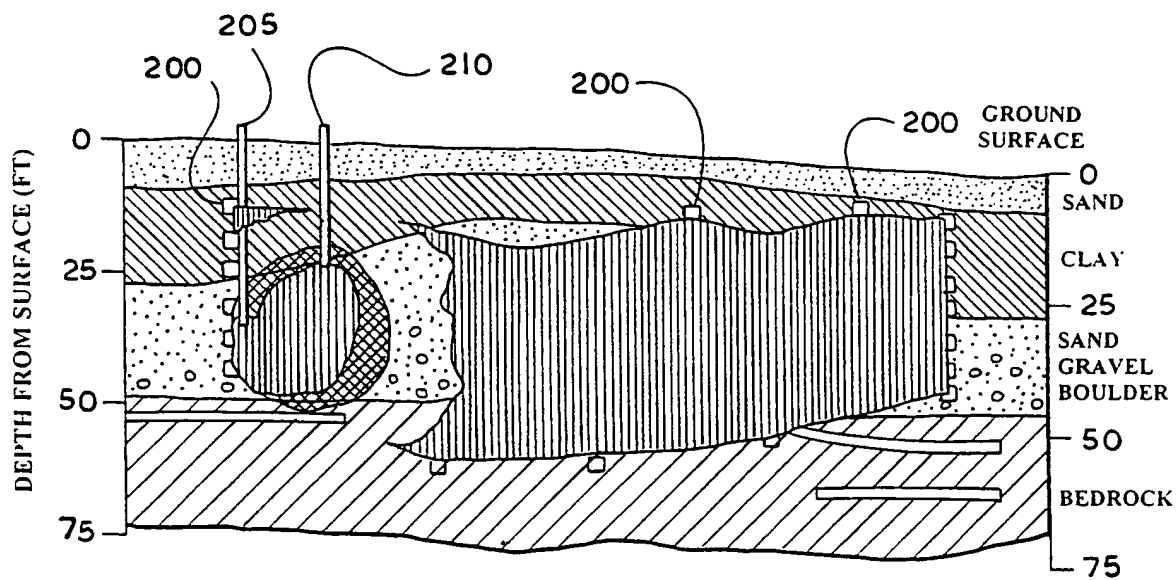


**Fig. 14**

SUBSTITUTE SHEET (RULE 26)



**Fig. 15**



**INDUCED VOLTAGES FROM PROPAGATING FRACTURE.**

**Fig. 16**

**THIS PAGE BLANK (USPTO)**



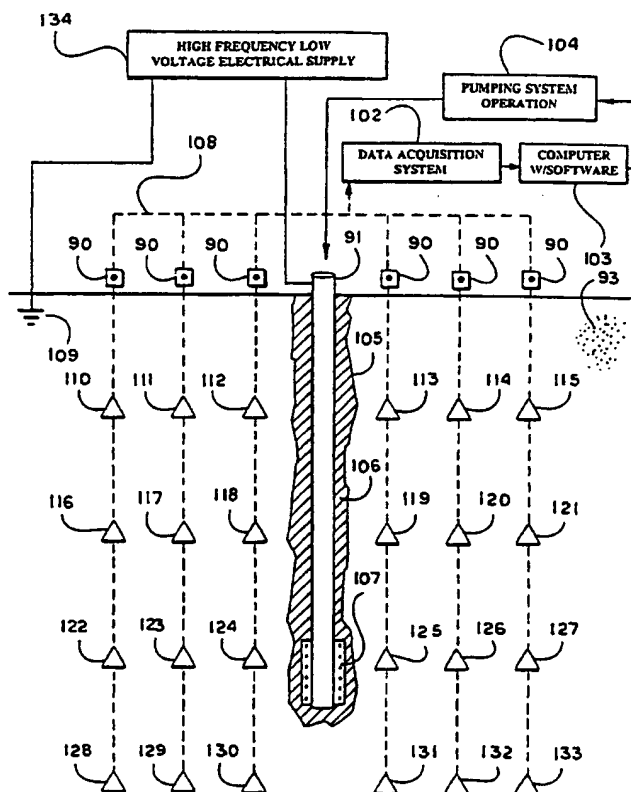
## INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(51) International Patent Classification <sup>7</sup> : E21B 43/26, 43/267, 47/12, G01V 3/20		A3	(11) International Publication Number: WO 00/29716
			(43) International Publication Date: 25 May 2000 (25.05.00)
(21) International Application Number: PCT/US99/27247		(81) Designated States: AU, CA, JP, European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE).	
(22) International Filing Date: 17 November 1999 (17.11.99)		Published With international search report.	
(30) Priority Data: 09/193,784 17 November 1998 (17.11.98) US		(88) Date of publication of the international search report: 16 November 2000 (16.11.00)	
(71) Applicant: GOLDER SIERRA LLC [US/US]; 3730 Chamblee Tucker Road, Atlanta, GA 30341 (US).			
(72) Inventors: HOCKING, Grant; 9315 Delft Way, Alpharetta, GA 30202 (US). WELLS, Samuel; 1212 Napoleon Manor, Lawrenceville, GA 30243 (US).			
(74) Agents: CHAN, Christopher, J. et al.; Jones & Askew, LLP, 2400 Monarch Tower, 3424 Peachtree Road, N.E., Atlanta, GA 30326 (US).			

(54) Title: AZIMUTH CONTROL OF HYDRAULIC VERTICAL FRACTURES IN UNCONSOLIDATED AND WEAKLY CEMENTED SOILS AND SEDIMENTS

## (57) Abstract

The invention is a method and apparatus for initiating an azimuth controlled vertical hydraulic fracture in unconsolidated and weakly cemented soils and sediments using active resistivity to monitor and control the fracture initiation and propagation. Separate or overlapping treatment walls and containment barriers can be created by controlling and monitoring the propagation of fractures in the subsurface. A fracture fluid is injected into a well bore to initiate and propagate a vertical azimuth controlled fracture. The fracture fluid is energized to conduct electrical current while the fracture propagates through the ground. A series of electrical resistivity monitors measure the electrical conductivity of the fracture fluid in real time against the background conductivity of the formation. Using a series of incremental influence functions, the azimuth of the vertical fracture can be controlled by regulating the injection of fracture fluid based upon the induced voltage of the earth and the conductivity of the fluid in the fracture.



**FOR THE PURPOSES OF INFORMATION ONLY**

Codes used to identify States party to the PCT on the front pages of pamphlets publishing international applications under the PCT.

AL	Albania	ES	Spain	LS	Lesotho	SI	Slovenia
AM	Armenia	FI	Finland	LT	Lithuania	SK	Slovakia
AT	Austria	FR	France	LU	Luxembourg	SN	Senegal
AU	Australia	GA	Gabon	LV	Latvia	SZ	Swaziland
AZ	Azerbaijan	GB	United Kingdom	MC	Monaco	TD	Chad
BA	Bosnia and Herzegovina	GE	Georgia	MD	Republic of Moldova	TC	Togo
BB	Barbados	GH	Ghana	MG	Madagascar	TJ	Tajikistan
BE	Belgium	GN	Guinea	MK	The former Yugoslav Republic of Macedonia	TM	Turkmenistan
BF	Burkina Faso	GR	Greece			TR	Turkey
BG	Bulgaria	HU	Hungary	ML	Mali	TT	Trinidad and Tobago
BJ	Benin	IE	Ireland	MN	Mongolia	UA	Ukraine
BR	Brazil	IL	Israel	MR	Mauritania	UG	Uganda
BY	Belarus	IS	Iceland	MW	Malawi	US	United States of America
CA	Canada	IT	Italy	MX	Mexico	UZ	Uzbekistan
CF	Central African Republic	JP	Japan	NE	Niger	VN	Viet Nam
CG	Congo	KE	Kenya	NL	Netherlands	YU	Yugoslavia
CH	Switzerland	KG	Kyrgyzstan	NO	Norway	ZW	Zimbabwe
CI	Côte d'Ivoire	KP	Democratic People's Republic of Korea	NZ	New Zealand		
CM	Cameroon			PL	Poland		
CN	China	KR	Republic of Korea	PT	Portugal		
CU	Cuba	KZ	Kazakstan	RO	Romania		
CZ	Czech Republic	LC	Saint Lucia	RU	Russian Federation		
DE	Germany	LJ	Liechtenstein	SD	Sudan		
DK	Denmark	LK	Sri Lanka	SE	Sweden		
EE	Estonia	LR	Liberia	SG	Singapore		

## INTERNATIONAL SEARCH REPORT

Inte onal Application No

PCT/US 99/27247

## A. CLASSIFICATION OF SUBJECT MATTER

IPC 7 E21B43/26 E21B43/267 E21B47/12 G01V3/20

According to International Patent Classification (IPC) or to both national classification and IPC

## B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC 7 E21B G01V

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal

## C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 3 280 913 A (SMITH) 25 October 1966 (1966-10-25) column 2, line 5 - line 43; figures 1,3-5	1
A	US 5 564 499 A (WILLIS ROGER B ET AL) 15 October 1996 (1996-10-15) abstract	1
A	US 4 875 015 A (WARD STANLEY H) 17 October 1989 (1989-10-17) the whole document	14,21
A	WO 94 05897 A (HGRC PTY LTD ;HOCKING GRANT (US); PHILLIPS STEVEN EDWARD (AU)) 17 March 1994 (1994-03-17) abstract	14,21
	-/-	

☒ Further documents are listed in the continuation of box C.☒ Patent family members are listed in annex.

## \* Special categories of cited documents:

- "A" document defining the general state of the art which is not considered to be of particular relevance
- "E" earlier document but published on or after the international filing date
- "L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
- "O" document referring to an oral disclosure, use, exhibition or other means
- "P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

Date of the actual completion of the international search

14 July 2000

Date of mailing of the international search report

26. 07. 2000

Name and mailing address of the ISA

European Patent Office, P.B. 5818 Patentlaan 2  
NL - 2280 HV Rijswijk  
Tel. (+31-70) 340-2040, Tx. 31 651 epo nl,  
Fax: (+31-70) 340-3016

Authorized officer

Fonseca Fernandez, H

## INTERNATIONAL SEARCH REPORT

International Application No  
PCT/US 99/27247

## C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 4 251 773 A (CAILLIAU MICHEL ET AL) 17 February 1981 (1981-02-17) -----	
A	US 2 952 319 A (POPHAM) 13 September 1960 (1960-09-13) column 3 -column 4; figures 4,5 -----	1
A	US 4 230 368 A (CLEARY JR JAMES M) 28 October 1980 (1980-10-28) abstract -----	1
A	EP 0 426 427 A (HALLIBURTON CO) 8 May 1991 (1991-05-08) abstract -----	1
A	US 4 420 974 A (LORD DAVID E) 20 December 1983 (1983-12-20) -----	
A	US 5 547 023 A (MCDANIEL BILLY W ET AL) 20 August 1996 (1996-08-20) -----	
A	US 4 483 399 A (COLGATE STIRLING A) 20 November 1984 (1984-11-20) -----	
A	US 4 119 151 A (SMITH HOMER GRAFTON) 10 October 1978 (1978-10-10) cited in the application -----	



# INTERNATIONAL SEARCH REPORT

International application No.  
PCT/US 99/27247

## Box I Observations where certain claims were found unsearchable (Continuation of Item 1 of first sheet)

This International Search Report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:  
because they relate to subject matter not required to be searched by this Authority, namely:
2. ☐ Claims Nos.:  
because they relate to parts of the International Application that do not comply with the prescribed requirements to such an extent that no meaningful International Search can be carried out, specifically:
3. ☐ Claims Nos.:  
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

## Box II Observations where unity of invention is lacking (Continuation of Item 2 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

see additional sheet

1. ☒ As all required additional search fees were timely paid by the applicant, this International Search Report covers all searchable claims.
2. ☐ As all searchable claims could be searched without effort justifying an additional fee, this Authority did not invite payment of any additional fee.
3. ☐ As only some of the required additional search fees were timely paid by the applicant, this International Search Report covers only those claims for which fees were paid, specifically claims Nos.:
4. ☐ No required additional search fees were timely paid by the applicant. Consequently, this International Search Report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

Remark on Protest

- ☐ The additional search fees were accompanied by the applicant's protest.
- ☒ No protest accompanied the payment of additional search fees.

FURTHER INFORMATION CONTINUED FROM PCT/ISA/ 210

This International Searching Authority found multiple (groups of) inventions in this international application, as follows:

1. Claims: 1-13

A method for creating vertical fractures at a predetermined azimuth in unconsolidated or weakly formations, where after drilling a bore hole and installing a casing, an injection fracture fluid is injected through a weakening line lying in said casing with a sufficient pressure to dilate said casing and initiate a vertical fracture in said formation.

2. Claims: 14-20,21-27

A method and apparatus for tracking a propagating vertical fracture in a formation of unconsolidated and weakly soil and sediments where a resistivity array comprising a plurality of individual resistivity receivers, spaced throughout said formation, has been installed to determine the incremental fracture geometry changes by measuring conductivity and induced voltages in the earth

INTERNATIONAL SEARCH REPORT  
information on patent family members

International Application No

PCT/US 99/27247

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 3280913 A	25-10-1966	NONE	
US 5564499 A	15-10-1996	NONE	
US 4875015 A	17-10-1989	AU 2260788 A WO 8900705 A	13-02-1989 26-01-1989
WO 9405897 A	17-03-1994	AU 3739293 A US 5944446 A	29-03-1994 31-08-1999
US 4251773 A	17-02-1981	FR 2395516 A AT 379456 B AT 458878 A AU 521230 B AU 3708278 A BR 7803997 A CA 1102875 A DE 2827229 A EG 14409 A GB 2001442 A, B IT 1096797 B JP 1017118 B JP 1544729 C JP 54045601 A MX 144380 A MY 19585 A NO 782149 A, B, SU 974940 A TR 20402 A ZA 7803417 A	19-01-1979 10-01-1986 15-05-1985 25-03-1982 20-12-1979 16-01-1979 09-06-1981 11-01-1979 31-03-1984 31-01-1979 26-08-1985 29-03-1989 15-02-1990 11-04-1979 05-10-1981 31-12-1985 28-12-1978 15-11-1982 10-06-1981 27-06-1979
US 2952319 A	13-09-1960	NONE	
US 4230368 A	28-10-1980	NONE	
EP 0426427 A	08-05-1991	US 5058676 A AT 115679 T CA 2028737 A DE 69015120 D DE 69015120 T NO 904682 A	22-10-1991 15-12-1994 01-05-1991 26-01-1995 04-05-1995 02-05-1991
US 4420974 A	20-12-1983	NONE	
US 5547023 A	20-08-1996	US 5431225 A EP 0703347 A NO 951580 A	11-07-1995 27-03-1996 22-03-1996
US 4483399 A	20-11-1984	NONE	
US 4119151 A	10-10-1978	NONE	

**THIS PAGE BLANK (USPTO)**